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# The Waterworks of Europe.

## III. LONDON AND LIVERPOOL.

A REPORT

PRESENTED TO

The City Councils of Philadelphia

BY

The Philadelphia Commercial
Museum.

June 30, 1899.

# The Philadelphia Commercial Museum.

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# WATERWORKS OF EUROPE.

## III. LONDON.

London, the capital of the British Empire, and center of commerce and finance for the entire globe, owes its origin to the site; and the geographical position explains much of its political importance, its unexampled growth and wealth. So complex is the aggregate, that there are officially more than a dozen Londons.

The former high mortality, as compared with modern results, was due largely to the unsanitary state of houses and streets; thus, taking the four worst years of the 17th century, 1603, 1625, 1636, and 1665, the average annual number who died of "plague" was 37,700 out of 54,200 deaths for all London; and in 1849, 14,125 died of cholera out of 68,800. The death-rate has in recent years been steadily diminishing from 24.3 per 1000 in 1855 to 21.6 in 1881, and 17.3 in 1887, so that London is more healthy than any of the twenty largest towns in England. The death-rate of all England is 20 per 1000, and France 22.8.

The present population numbers about 6,000,000.

### London Waterworks.

After the Conquest, London obtained a sufficient supply of water, partly from the rivers and streams which passed through it, and partly from wells sunk into the sands and gravels above the London clay. Holywell, Clerk's well (Clerkenwell), and St. Clement's well (near Clement's inn) are mentioned by Fitzstephen as those "of most note." In 1236 the Magistrates purchased from Gilbert Sandford the liberty to convey the waters of the Tyburn from Paddington in leaden pipes to the city, and a great conduit of lead, castellated with stone, was begun in Eastcheap in 1285. Various other conduits were built in the 14th and 15th centuries, some for the water of the Thames, from which also the inhabitants were supplied by the City Company of Waterbearers, who brought it in leather panniers slung on horses.

In 1582 a great step in advance was taken by Peter Moris, a Dutchman, who erected a forcier on an arch of London Bridge to convey the Thames water into the houses in the east end of the city as far as Gracechurch Street; in 1594 another was erected near Broken Wharf for Westcheap, Fleet Street, and the district around St. Paul's; and in 1610 a third at Aldersgate, outside the gate. Moris, who obtained the lease of an arch on London Bridge for 500 years at a rental of 10s. per annum, and two years later the use of another arch, erected for his purpose very ingenious machinery; and the works continued until 1701 in possession of his family, who, after amassing large wealth, sold the lease to a company for $150,000.

This company ultimately occupied four arches, and continued until 1822, when the works were removed just before the demolition of old London Bridge, and the property was sold to the New River Company.

Dr. Sisley, in his interesting and accurate book upon the London water supply, recently published, gives an excellent account of the early history of the supply, and describes the state of the London Bridge Waterworks Company in the beginning of this century as follows:

"The quantity of water supplied by the Company in 1610 was estimated at something between 3,000,000 and 4,000,000 gallons daily, and the water-wheels worked for about twenty hours each day. When the tide was very low, less water was raised by water-power, and the necessary quantity was made up by working a steam engine. The superintendent of the Company gave a somewhat depressing account of the state of business in the year 1821. They had at that time a very 'strong enemy' against them, which had taken away many of their customers. 'They were in a state of pauperism, and much to be pitied.' The 'strong enemy' was the New River Company, which had the power of raising water higher than the London Bridge Company could possibly do. The new fashion of building high houses was disastrous to the Company, because cisterns and water-closets were placed at an unreasonable distance above the ground in the new buildings. The distributing pipes used by the Company were made of wood, and they had not money enough to replace them by iron ones. They were unable to supply the water at a higher level than the second story of a house. The superintendent of the Company would not admit that the water supplied was of a bad quality, and he said that in many instances distillers took it in preference to any other, but he said he never thought of drinking it in the condition in which it was supplied. The ebb tide, he admitted, brought down a considerable quantity of soil from the rivers which ran into the Thames, and the water was frequently foul, but after it had stood in a cistern for twenty-four hours it became 'finer than any other water that could be produced.' For his own supply the superintendent had two large cisterns, and by drawing out the water alternately every other day he had 'as clear water as could be imagined.'

"The rates charged for supplying the tenants of the London Bridge Waterworks varied, according to the amount supplied, from a minimum of less than £1 to a maximum of over £20 per annum. The total number of customers was a little over 10,000, and sixty-eight public buildings were supplied. The method of arranging as to the price charged to customers was that the surveyor first examined the premises closely, and reported to the superintendent what he thought the consumption was likely to be, and the size of the service-pipe. The price was then fixed, and if in the course of time it was found that the consumption was more or less than had been estimated, an abatement or increase in the sum charged was made, according to the circumstances of the case. Brewers, stable-keepers, and some other tradesmen were subject to an extra charge. The amount of water considered necessary for a daily supply to a house was one butt, and any quantity above that was considered 'extra service.'

"With regard to the ultimate failure of the London Bridge Waterworks, it may be said to have been due not so much to complaints as to the quality of the water supplied, as to the fact that the New River Company were able to supply water at a higher pressure, which enabled them to force it to the upper stories of the London houses."

The Corporation of the City of London obtained an act to convey water from Hertfordshire to the city in 1606, and a supplemental act in the following year, but failed to avail themselves of their provisions. The works contemplated under these acts were undertaken in 1609 by Hugh Myddleton, who, when his funds became exhausted in 1612, received the necessary money from King James I., on condition that he should share in the profits. This was the commencement of the prosperous enterprise since known as the New River Company. The Chelsea Company was founded in 1721, the Vauxhall Company in 1805, the West Middlesex and East London Companies in 1806, the Kent in 1810, the Grand Junction in 1811, and the Southwark in 1822.

The history of all these companies reveals the fact that the municipal and local authorities were unwilling to undertake the risk of supplying London with water, leaving it to be carried out by private enterprise, which, in this way, as in so many other ways, has proved itself to be the great factor in promoting the material interests of the country. This fact is apt to be forgotten or hidden from view by the apostles of the new school of Socialistic doctrinaires, who seek to repress individuality and depreciate self-interest, which, when properly regulated, has, nevertheless, been one of the most powerful motives for the advancement of mankind.

Having thus briefly traced the history of the London water supply, we turn to the consideration of its extent in the present day. The subject appears to divide itself naturally into six heads:

1. The area and population to be supplied.
2. The quantity of water supplied.
3. The sources of supply and the quantity taken from each source.
4. The works for the storage, filtration and distribution of the water by the companies for the supply of their several districts.
5. The quality of the water.
6. The supply in the future.

### 1. THE AREA AND POPULATION SUPPLIED, OR WHICH MUST EVENTUALLY BE SUPPLIED.

The area supplied by the eight metropolitan water companies, under their Parliamentary powers, is generally known under the name of Water London, and has a total area of 620 square miles. It extends from Amwell (near Hertford) in the north to Croydon in the south, and from Hampton in the west to Ilford in the east. Its population in 1891 was about 5,237,000, and is now estimated at about 5,800,000, having increased from 958,863 at the beginning of the century.

Water London contains within it the administrative county of London, and is coextensive with the area called Registration London by the General Register Office, with the addition of the hamlet of Penge.

Greater London is the area included within the Metropolitan and City Police districts. It includes all parishes wholly situated within a circle of 15 miles radius from Charingcross, and all parishes of which any part is included within a circle of 12 miles radius from the same center. Its total area is 701 square miles, and its population in 1891 was 5,633,332. It is this area and population, with the addition of the area and population of Water London which lies outside it, which Lord Balfour's commission took into consideration when framing their valuable and exhaustive report in 1892-3. But perhaps the best idea of the gigantic problem of the London water supply can be obtained by the knowledge that the population to be supplied is equal to the aggregate population of the following cities and towns in the United Kingdom, viz.: Glasgow, Birmingham, Liverpool, Manchester, Salford, Edinburgh, Dublin, Belfast, Leeds, Sheffield, Aberdeen, Dundee, Bath, Bristol, Southampton, Northampton, Nottingham, Newcastle, Bradford, Cardiff, Swansea, Blackburn, Halifax, Derby and Brighton. Such a fact speaks for itself without comment.

The supply to Water London is given mainly by the eight metropolitan water companies, viz., the Chelsea, East London, Grand Junction, Lambeth, Kent, New River, Southwark and Vauxhall, and West Middlesex Companies.

In addition, outside the Parliamentary districts of these companies and wholly or partly within the area of Greater London, the following ten companies and local authorities give supplies:

The Barnet District Gas and Water Company.
The Central Middlesex Water Company (Alperton and Sudbury).
The Colne Valley Company.
The East Surrey Company.
The Epsom Local Board.
The Rickmansworth Company.
The Southwest Suburban Company.
The Sutton Company.
The Uxbridge Local Board.
The West Surrey Company.

Such being the area and population supplied, we proceed to consider the quantity of water supplied.

## 2. THE QUANTITY OF WATER SUPPLIED.

As the quantity supplied by these smaller bodies was estimated by Mr. Balfour's commission to be not more than 10,000,000 gallons daily, we propose to neglect them and to confine our attention to the eight metropolitan water companies.

The average daily quantity of water supplied in 1897 by the eight metropolitan water companies, the population supplied and the average daily supply per head are given in the following table:

| Company. | Population supplied. | Average daily supply, in gallons. | Average daily supply per head. | Sources. |
|---|---|---|---|---|
| East London . . . | 1,261,732 | 41,036,732 | 32.52 | Lea, Thames and wells. |
| New River . . . . | 1,176,363 | 35,974,488 | 30.58 | Lea, wells and springs. |
| Southwark and Vauxhall . . . | 809,320 | 33,767,401 | 41.72 | Thames and wells. |
| Lambeth . . . . | 666,981 | 23,688,305 | 35.51 | Thames. |
| West Middlesex . | 601,509 | 20,337,019 | 41.72 | " |
| Kent . . . . . | 512,412 | 15,482,056 | 29.94 | Wells. |
| Grand Junction . | 398,396 | 19,532,580 | 49.03 | Thames. |
| Chelsea . . . . . | 276,691 | 12,283,789 | 44.32 | " |
| Total . . . . . | 5,703,404 | 202,102,544 | 35.43 | |

Total supply, 1897, 73,767,428,465 gallons.

3. THE SOURCES OF SUPPLY.

The sources of supply are: (a) The Thames and gravel beds adjacent to the river; (b) the Lea and springs in the Lea Valley; (c) thirty-two wells in the chalk formation.

In 1897 the average daily quantities supplied from the sources were as follows:

| Sources. | Gallons. | Percentage of whole supply. |
|---|---|---|
| From the Thames . . . . . | 112,178,641 | 55.51 |
| From the Lea . . . . . | 55,292,863 | 27.36 |
| From springs and wells . . . . . | 34,488,016 | 17.06 |
| Hampstead and Highgate ponds (non-domestic) . . . . . | 143,024 | 0.07 |
| Total . . . . . | 202,102,544 | 100.00 |

Having thus given the leading facts of the water supply of London, we proceed to the consideration of our fourth division of the subject.

4. THE DISTRICTS OF THE SEVERAL COMPANIES AND THE ARRANGEMENT OF THEIR WORKS FOR STORAGE, FILTRATION AND DISTRIBUTION. THE NEW RIVER COMPANY.

The New River Company was incorporated by Royal charter in the reign of King James I., the charter prohibiting any interference with the New River, or the bringing to the cities of London and Westminster and the borough of Southwark water from any place whatsoever without the license of the New River Company. The powers of the company have since been altered by Acts of Parliament passed at different times.

The company's district of supply includes the city of London (with a few exceptions in Bishopsgate and Aldgate, supplied by East London Company), Edmonton, Enfield, Hornsey, Tottenham in Middlesex, and in Hertfordshire, Broxbourne, Cheshunt, Great and Little Amwell, Hoddesdon, St. Margarets, Ware, Wormley and St. Johns without the borough of Hertford.

It should, however, be noted that in Middlesex the District Councils of Enfield and Tottenham have independent sources of supply, while very few supplies are given to the parishes in the county of Hertford. This district is colored red upon the cartoon, which clearly shows its general extent and boundaries. The average population supplied in 1897 was 1,176,363, the average daily supply being 35,974,488 gallons.

The New River Company derive their principal supply from the Lea, the intake being situated between Hertford and Ware Locks. Under the River Lea Water Act of 1855 a quantity of about 5,400,000 gallons daily is reserved for the navigation, and as much as may be necessary in addition to keep up the head of water in each level of the river.

The New River Company have a preferential right to take 22,500,000 and the East London Company to take 22,500,000. When these demands are satisfied the two companies are empowered pari passu to take all the remaining flow of the stream. A balance gauge has been constructed at the intake which regulates the quantity taken by the New River Company to 22,500,000 gallons a day, the quantity to which, under arrangement with the East London Company, the company at present limit their supply.

The New River is about twenty-six miles long, and commences at the Chadwell Spring between Hertford and Ware, being shortly joined by an artificial cut bringing the supply from the River Lea. It runs through Broxbourne, Cheshunt, Enfield and Southgate to Hornsey; thence to Stoke Newington, where the principal works of the company are situated, and ends at the New River Head, Clerkenwell. At intervals between Chadwell Spring and Hornsey are the following wells, with pumping machinery for raising water from the subterraneous reservoirs in the chalk into the river channel: Broadmead well above Ware, Amwell-end well at Ware, Amwell Hill well below Ware, Amwell Marsh well between Ware and St. Margarets, Rye Common well at St. Margarets, Hoddesdon well, Broxbourne well, Turnford well be-

tween Broxbourne and Cheshunt, Cheshunt well, Hoelane well above Enfield, White Webbs well at Enfield, Highfield well at Edmonton, Campsbourne well at Hornsey, Betstile well at New Southgate.

The New River Company have also deep wells at Hampstead Heath, at Hampstead Road and at Bush Hill Park, Edmonton; but these wells have no pumping machinery.

In addition to the above sources of supply the New River Company will have the right to take 11,667,000 gallons daily from the Thames when the Staines Reservoir Works are completed.

The company have at Cheshunt two storage reservoirs, with a joint capacity of 39,000,000 gallons, which can be filled from the adjoining well.

At Hornsey 7,000,000 gallons daily pass from the river through subsiding and storage reservoirs, with a total available capacity of 8,500,000 gallons, into eight filter beds having a total filtering area of 5¼ acres, whence the water is pumped to service reservoirs at Crouch Hill, Bourne Hill, Maiden Lane and Hornsey Lane. From Hornsey the river flows to Stoke Newington, where the principal works of the company are situated. The water flows through two subsiding and storage reservoirs, with a total available capacity of 90,000,000 gallons, on to nine filter beds with a total area of 9 acres, whence a daily average of about 19,000,000 gallons is pumped by one compound Worthington and six compound beam-pumping engines to the service reservoirs at Crouch Hill and Maiden Lane for distribution into the town district of the company.

The remainder of the water travels on to the end of the channel at the New River Head, Clerkenwell, where it passes through a subsiding reservoir on to three filter beds with a total area of 2¼ acres, from which about 6,000,000 gallons daily are raised to a service reservoir in Claremont Square.

The capacities and levels at the full water lines of the various reservoirs are as follows:

| Reservoirs. | Capacity in gallons. | Feet above O. D. |
|---|---|---|
| Claremont Square | 3,500,000 | 139.00 |
| Crouch Hill | 12,000,000 | 195.50 |
| Bourne Hill | 1,500,000 | 195.50 |
| Maiden Lane | 15,000,000 | 232.00 |
| Hornsey Lane | 3,000,000 | 348.20 |
| Southgate | 1,000,000 | 308.00 |
| Highgate | 1,000,000 | 432.50 |
| Hampstead | 500,000 | 446.20 |
| Total | 35,500,000 | |

At three of the reservoirs there are standpipes, by pumping into which water can be supplied to further heights, as under:

| Reservoirs. | Feet above O. D. |
|---|---|
| Claremont Square | 185.00 |
| Highgate | 481.80 |
| Hampstead | 486.30 |

There are also at Hampstead and Highgate ponds having a total available capacity of 29,000,000 gallons, from which separate pipes supply street watering posts and other non-domestic services.

This company are also constructing works at Hansworth and laying a 36-inch main to convey to their district the 11,667,000 gallons of daily supply, which will be available from Staines. These works are being designed and are under the direction of Mr. J. Francis, M. Inst. C. E.

## The East London Waterworks Company.

The East London Waterworks Company was established in 1808 and authorized to purchase two existing waterworks, one situated at Shadwell, started in 1669, the other at West Ham, started in 1747. The company constructed settling reservoirs at Old Ford, with an area of about eleven acres, which were supplied from the River Lea within tidal influences. A service reservoir was also constructed at Mile End, with the necessary pumping machinery. In 1829 the company purchased the Hackney Waterworks and Lea Bridge Mills, and obtained an Act to enable them to remove their intake from Old Ford to Lea Bridge, whence the water was brought to the Old Ford reservoirs by an open conduit, and thence pumped for use. In 1852 and 1853 the company's district was defined, and authority was obtained to make a new cut in connection with the River Lea for improving the quality of the water, to construct large impounding reservoirs at Walthamstow and filter beds at Lea Bridge, and to make an intercepting cut on the western side of the Lea from Tottenham to beyond Ponder's End for the purpose of preventing polluted water from entering the river above the company's intake. In 1852 and 1862 Acts were passed for increasing the capital of the company. In 1867 an Act was passed enabling the company to construct a covered service reservoir in Finsbury Park, and to establish works at Sunbury and Hanworth, with the necessary engines and mains to convey 10,000,000 gallons a day from the Thames to the company's district. In the same year a separate Act gave powers to increase the number of reservoirs at Walthamstow and filter beds at Lea Bridge, to fill up the open reservoirs at Old Ford and to cease using the open canal communicating with the open reservoirs and the works at Lea Bridge. In 1881 and 1886 Acts were passed for increasing the

capital, and in the latter Act the company took power to sink wells and to construct further works to guard against pollution above their intake. The works at Old Ford were finally abandoned early in 1892.

The places and parishes in which the East London Company are by their Acts authorized to supply water are as follows:

**Middlesex**—Whitechapel, Mile End Old Town, Mile End New Town, Spitalfields, Bishopsgate, Artillery Ground, Aldgate, St. George's East, Shadwell, Limehouse, Wapping, Ratcliff, St. Luke Old Street, Stoke Newington, Bow, Bromley, Stepney, Poplar, Bethnal Green, Shoreditch, Hackney, Tottenham, Old Ford, Homerton, Clapton, Kingsland, Shacklewell, Holloway, Stamford Hill and Dalston.

**Essex**—West Ham, East Ham, Low Leyton, Leytonstone, Leyton, Walthamstow, Waltham Abbey, Waltham Cross, Ilford, Stratford, Dagenham, Wanstead, Woodford, Chigwell, Loughton, Chingford and Barking.

SOURCES OF SUPPLY.

The company takes its supply of water from four separate sources:

1. From the River Lea, the intakes being at Enfield Lock and Ponder's End.
2. From deep wells in the chalk at Walthamstow, Chingford, Lea Bridge and Waltham Abbey. Three additional wells are being sunk at Rammey Marsh, Ponder's End and Barking.
3. From the River Thames at Sunbury.
4. From springs at Hanworth.

The company's works are ten in number, situated at Lea Bridge, Walthamstow, Chingford Hill, Woodford, Buckhurst Hill, Hornsey Wood, Sunbury, Hanworth, Walthan Abbey and High Beach.

**Lea Bridge.**—The water flows from the reservoirs at Walthamstow in an open channel 1¼ miles long to the filter beds, of which there are twenty-five, with a total area of 24 acres. The filtered water is pumped into the district by ten engines and four turbines, with an aggregate horse-power of 2710. There is a deep well in the chalk whence water is pumped by an engine of 250 horse-power. The chief offices of the engineering department, stores, testing and work shops are at this station.

**Walthamstow.**—At this station are ten storage reservoirs, with a total capacity of 1,215,000,000 gallons. The reservoirs are fed from the Lea at Enfield Lock and Ponder's End, the two conduits joining a short distance above Chingford Mill. Three reservoirs are high level and three low level. The former receive their supply from the head and the latter from the tail of Chingford Mill. Powers were taken by the Act of 1897 to construct additional reservoirs of 1,000,000,000 gallons capacity, and the company are promoting a bill in the present Parliamentary session for about 5,000,000,000 gallons of additional storage, and other works at a total cost of £1,500,000.

At this station a well has been sunk into the chalk, whence water is pumped by a 250 horse-power engine, which a 350 horse-power engine pumps eastward to Hagger Lane and westward to Hornsey Wood reservoirs.

**Chingford Mill.**—Here are two wells, from one of which the water is pumped by turbines to Woodford under a pressure of 230 feet, while a quadruple expansion engine pumps the water from the other well.

**Woodford.**—These works comprise two covered service reservoirs of a joint capacity of 3,000,000 gallons, the head water level being 171 above O. D., and two engines, each of 60 horse-power, for pumping to the higher districts.

**Buckhurst Hill.**—A water tower of 70,000 gallons, with an altitude of 328 above O. D., was erected in 1879, and a service reservoir containing 7,000,000 gallons has recently been completed.

**Hornsey Wood.**—This reservoir is situated in Finsbury Park, has 5,000,000 gallons capacity, and is connected with the Thames supply and with the Lea Bridge works. Its height is 142 feet above O. D.

**Sunbury.**—The intake is in the county of Surrey in an islet in the Thames above Sunbury Lock. Two engines, of 75 horse-power each, pump the unfiltered water to Hanworth, about two miles.

**Hanworth.**—The unfiltered water from Sunbury is delivered into an open reservoir containing about 5,000,000 gallons, whence it flows on to six filter beds, having a joint area of five acres, and from the filters into two covered reservoirs, having a joint capacity of 2,500,000 gallons. Underground water is obtained from gravel beds, in which collecting tunnels have been driven. Five engines, of 630 total horse-power, force the water over a tall standpipe, and through about 19 miles of 36-inch main to the Hornsey Wood reservoir in Finsbury Park, whence it gravitates over the company's western district.

**Waltham Abbey.**—A deep well has here been sunk into the chalk, whence the water is pumped by triple-expansion engines to the surface of the ground and thence to the High Beach reservoir.

**High Beach Reservoir.**—The reservoir, which can be filled either from Waltham Abbey or from Woodford, is situated in Epping Forest, near to the King's Oak. Its capacity is 2,500,000 gallons, its altitude 371 feet above O. D., and it supplies the company's high-level district in Essex.

The East London now supplies more water than any of the other London companies, their average daily supply in 1897 being 41,036,906 gallons, distributed to a population numbering 1,261,732.

## The West Middlesex Waterworks.

The company was incorporated in 1806 by Act of Parliament, which empowered them to supply with water the parishes of St. Paul's, Hammersmith; All Saints', Fulham; St. Mary Abbott's, Kensington; St. Nicolas',

Chiswick, with other parishes in the county of Middlesex, and also certain parishes in the county of Surrey, to which, however, the company did not give any supply. By a further Act of 1810 the limits of supply were enlarged and by another Act of 1866 the district was extended to the parishes of St. John's, Hampstead; Hendon, Willesden, and a small portion of Acton—all in Middlesex.

DESCRIPTIVE SUMMARY OF THE WORKS.

The intake of the company from the Thames is at Hampton, where there are a pair of engines, 900 horse-power, capable of delivering 32,000,000 gallons per day, and one engine of 400 horse-power, capable of delivering 24,000,000 gallons per day into the subsiding reservoirs at Barnes, a distance of nine miles, through two 36-inch cast-iron mains.

At Barnes there are seven subsiding reservoirs, with a total available capacity of 397,000,000 gallons, four of which have recently been constructed upon the recommendation and to the designs of Mr. Hervey, M. Inst. C. E., the company's engineer, and eleven filter beds, having a filtering area of 4 acres, are in course of construction. The water is filtered through a stratum of washed sand 2 feet 9 inches thick, superposed upon a stratum of various sized stones 1 foot in thickness.

At Hammersmith, the station on the Middlesex side of the Thames, the water is pumped for the supply of the whole district. The water gravitates from Barnes to the engine wells through a channel 8 feet in diameter, which has recently been constructed under the bed of the river.

The engine-power available is 1605 horse-power, capable of pumping 30,000,000 gallons daily. Nearly the whole of the district is supplied by direct pumping by means of three 30-inch mains, two 21-inch mains, one 14-inch main and one 10-inch main. Three service reservoirs are also supplied from Hammersmith at Kensington, Barrow Hill and Willesden. The higher parts of the country district are supplied by pumping a second time at Barrow Hill and Willesden.

At Barrow Hill the available engine-power is 180 horse-power, capable of pumping 6,000,000 gallons per day by means of three trunk mains, two 15-inch and one 16-inch in diameter. The service reservoirs supplied from Barrow Hill are at Kiddepore and Shoot-up-Hill. At Willesden the available engine-power is 84 horse-power, capable of pumping 4,000,000 gallons daily by means of a main 16 inches in diameter running to the service reservoir at Shoot-up Hill.

The situation, capacity and elevation of the service reservoirs are as follows :

| Reservoirs. | Height above Ordinance Datum. | Capacity in gallons. |
|---|---|---|
| Kensington, Campden Hill . . . . . | 120 | 3,672,000 |
| Barrow Hill, by Primrose Hill . . . . . | 190 | 4,750,000 |
| Willesden, Harlesden . . . . . | 190 | 2,500,000 |
| Shoot-up-Hill, Mill Lane, by Edgware Road . . | 257 | 6,000,000 |
| Kiddepore, Platt's Lane, by Finchley Road . . | 323 | 2,500,000 |
| Total . . . . . | | 19,422,000 |

The above filtered-water reservoirs are all covered. All engines and trunk pumping mains are in duplicate. The total quantity of water that may be drawn from the River Thames, by agreement with the Thames Conservancy, is 24,500,000 gallons per day, to which will be added a further supply of 11,667,000 gallons daily when the Staines Reservoir Works are completed. The average daily supply in 1897 was 20,337,019 gallons, distributed to a population of 601,509.

## The Grand Junction Waterworks Company.

The company was incorporated by Act of Parliament in 1811, which transferred to the company Parliamentary powers for supplying certain western districts of the metropolis, under the Act granted to the Grand Junction Canal Company in 1798. The original works were situated at Paddington, and the supply was taken from the canal till 1826, when the source of supply was removed to the River Thames at Chelsea. In 1835 the intake was removed to the works at Kew Bridge. In 1852 the company's source of supply was removed to its present position at Hampton.

**Area of Supply.**—The company's area of supply includes the parishes of Paddington, Kensington, Marylebone, St. George's, Hanover Square, St. James, Westminster, Hammersmith, Brentford, Ealing, Chiswick, Acton, Hanwell, Isleworth, Twickenham, Teddington, Hampton Wick, Hampton Court, Bushey Park, Whitton, Hanworth and Heston, all in the county of Middlesex.

### DESCRIPTION OF WORKS.

The works are situated in the Hampton and Sunbury parishes, Middlesex, upon the north side of the Thames, at Kew Bridge, at Campden Hill, and at Ealing. The intakes from the River Thames are at Hampton.

The old intake, constructed in 1853, is situated opposite Platt's Islet, about a quarter of a mile above Hampton Church, and consists of two 36-inch pipes, with sluices. This intake delivers water direct into the low-level filters for the supply of the country districts and to the "bull engines," which formerly pumped the water to Kew but are now held in reserve for use upon emergency.

The new intake is situated about one mile higher up the river, upon an islet opposite Kenton Court, where a chamber, commanded by sluices and protected by a grating, has been built, and is connected by 30-inch pipes to a chamber on the north bank of the river. The top of these chambers is raised to a level above the level of the highest recorded flood. From the second chamber the water is conveyed by two 36-inch pipes, laid under the lower Sunbury Road to the wells of the low-lift pumping engines, about half a mile distant.

**Gravel Beds.**—In a 10 acre field immediately opposite the new intake, but upon the north side of the lower Sunbury Road, the gravel beds form a natural filter, from which the water is drawn through 24-inch drain pipes, with open joints, connected with the third line of pipes, 30 inches in diameter, laid along the lower Sunbury Road to the works, and these can also be connected direct to the river. A channel has been formed in the center of the field, through which the land can be charged with water from the river when desirable. The bottom of the channel is constructed as a filter, the sand of which can be removed and washed when necessary. These gravel beds are treated by the company and recognized by the Water Examiner as practically an addition to their storage resources.

The works at Hampton consist of a storage and subsidence reservoir having a capacity of 45,000,000 gallons. A large proportion of the supply from the river is pumped into this reservoir, whence it is drawn off through two water towers provided with sluices, so that the water may be drawn off from the surface, whatever may be its level. The total area of filters at Hampton is 15¾ acres. The filters are generally constructed as shown by the type diagram upon the wall. The filtering material consists of washed sand, 3 feet in thickness, resting upon gravel and stones 2 feet thick, gradually increasing in size toward the bottom of the filter. As the stones in the gravel found upon the works were not sufficiently large, the concrete bottom of the filter has 2-inch drain pipes, 1 yard apart, laid over it, which run to the collecting main in the center. The water is delivered into the filters by a bell-mouthed pipe, just above the top sand level. It flows over the surface of the sand to the depth of about 5 feet, and passes through the sand and the gravel into the collecting drain, running along the center of the filter bed, whence it is delivered through cast-iron pipes to the engine wells. Valves are provided for regulating the supply and delivery of the water, so that the water shall pass through the filtering medium at a rate not exceeding a maximum of 2½ gallons per square foot of filtered surface per hour.

The country district is supplied from the Hampton Works by a pair of compound beam engines and a "Davy" engine, to which a vertical triple-

expansion engine is now being added. The water is pumped through one 30-inch and one 12-inch main running through New Hampton into the Twickenham Road, along which the 30-inch main proceeds past the Kew Works, to which it has two connections. It then supplies part of Shepherd's Bush, and is finally connected into the Campden Hill Reservoir. The 12-inch main, after diverging through Twickenham, follows the same course to Turnham Green, whence it passes through Goldhawk Road and Uxbridge Road and finishes in Ladbroke Grove by a connection to the Kew 30-inch main.

**Kew Bridge Works.**—The water is pumped from Hampton to Kew through two 33-inch mains, one running along the Twickenham Road, through Isleworth to Kew Bridge; the other through New Hampton, past Hospital Bridge, and through Whitton and Isleworth to Kew Bridge, which it enters at the back of the works. This latter main will also be used for the supply of the western part of the district as the population increases.

At the Kew Bridge Works there are one upper reservoir, 8,500,000 capacity; one lower reservoir, 5,000,000 capacity; eight filter beds, 8¾ acres area; one filter water reservoir (covered), 2,500,000 capacity.

From the Kew Bridge Works the town district is supplied by two 30-inch mains, one running almost due east through Turnham Green and Bedford Park, along Uxbridge Road (with a branch to Campden Hill and Oxford Street), terminating near Poland Street; the other 30-inch main turns up Gunnersbury Lane (whence there is a 30-inch main to Ealing Reservoir), Acton, Ladbroke Grove, Nottinghill Gate, Grand Junction Road, and finishes in the Edgware Road, where it is connected with a 24-inch main, supplied from Campden Hill.

**Engines.**—There are eight pumping engines at these works, having a pumping capacity of about 26,000,000 gallons in twenty-four hours.

**Ealing Works.**—At Ealing, upon the top of Hanger Hill, the company possess a service reservoir for filtered water, having a top water level of 205 feet above O. D., and having a capacity of 3,000,000 gallons, and a large storage reservoir containing 50,000,000 gallons, having its top water level 193.5 feet above O. D. For the supply of the higher part of the neighborhood a water tower with cast-iron tank on the top, having a top water level of 265 feet above O. D., has been erected.

**Campden Hill Works.**—At these works there are three filtered water storage reservoirs, having a total capacity of 18,000,000 gallons, and three pumping engines capable of raising about 20,000,000 gallons daily into a standpipe to a level of 270 feet above O. D. The supply of the high-level district of the company is given from these works.

**Powers of Supply.**—The company has statutory powers to take from the Thames any water that is required for the purposes of their district. Under the agreements of 1852 and 1886 with the Thames Conservancy these powers are at present exercised to an extent not exceeding 24,500,000 gallons

daily. When the Staines Reservoir Works are completed the company will have additional supply of 11,667,000 gallons daily. The average quantity of water supplied daily in 1897 was 19,532,580 gallons to a population of 398,390.

## Chelsea Waterworks Company.

The company's intake is situated at West Molesey, in the county of Surrey, on the south bank of the Thames, the Thames being the only source of supply. The works consist of the intake, pumping power equal to 35,000,000 gallons, and four reservoirs, whence it is delivered to the Surbiton Works by gravitation. These reservoirs have a total capacity of 140,000,000 gallons, but are now being enlarged to contain 189,000,000 gallons under the direction and to the design of Mr. R. Hack, M. Inst. C. E. The water is delivered from Molesey to Surbiton through two 36-inch mains. The works at Surbiton contain 8 acres of filtering area and pumping power equal to 22,000,000 gallons in twenty-four hours, which allows of a large margin of reserve for any contingency. From Surbiton the filtered water is pumped to Putney Heath through three mains, one of 30-inch diameter for the whole distance, one 30-inch reduced to 24-inch on the top of Kingston Hill, and one 15-inch main. The storage capacity of the filtered water reservoir at Putney Heath is 11,000,000 gallons, which capacity is being doubled by works now under construction. The top water level reservoirs are 175 feet above O. D., which can be increased to 197 feet above O. D. by pumping over a standpipe.

**Distributing Mains.**—From the service reservoirs on Putney Heath there are five trunk lines of distributing mains. These mains, of which three are of 30-inch diameter and two of 15-inch, cross Putney Heath and enter the main road at the top of Putney Hill. At this point they are reduced in diameter to 24-inch and 12-inch respectively, and passing down Putney Hill, cross the Southwestern Railway by an aqueduct bridge and the Thames beneath the footways of Putney Bridge. From the north end of Putney Bridge three 24-inch, one 18-inch and two 12-inch mains distribute the water over the whole of the district of the company.

**District of Supply.**—The Chelsea Company's district of supply is situated wholly within the metropolis, consisting of an area of 5 square miles, extending from Charing Cross to the "Crabtree," Fulham, and bounded by the River Thames on the south, and on the northeast and northwest by the Grand Junction, New River and West Middlesex Companies. The population supplied was 276,691 in 1897, and the average daily quantity of water supplied was 12,079,000 gallons.

The company have power to abstract 22,000,000 gallons of water daily from the Thames, which gives a large surplus beyond that required for the present supply of the district. It is estimated that the eventual maximum daily supply when the company's district is entirely built over will not exceed 17,500,000 gallons.

## Lambeth Waterworks Company.

The area of supply of this company consists of the parishes of Thames Ditton, Esher, Long Ditton, Kingston, Putney, Malden, Marden, Wimbledon, Merton, Morden, Tooting Graveney, Clapham, Wandsworth, Battersea, Streatham, Croydon, Newington Butts, Newington, Bermondsey, Camberwell, Lambeth, Horselydown, St. Saviour's, St. George the Martyr, Christchurch, St. Olave, St. Thomas, the Clink Liberty in Southwark, and such parts of Beckenham and Lewisham as lie on the western side of the River Ravensbourne.

**Works.**—The principal intake of the company from the Thames is at West Molesey, where there are a pair of pumping engines of 100 horse-power and a pair of engines working two centrifugal pumps, the total engine-power being capable of pumping 42,500,000 gallons per day into the subsiding reservoirs or into the conduit hereafter mentioned, as occasion may require. The present storage capacity of the reservoirs is 125,000,000 gallons, which is now being increased to 465,500,000 gallons by the advice and to the designs of Mr. T. F. Parkes, M. Inst. C. E. The company have powers to take 24,500,000 gallons daily from the Thames, while an additional quantity of spring water can be obtained from under the land at the Molesey Works to the extent of from 6,000,000 to 8,000,000 gallons daily. From the reservoirs the water flows by gravitation, a distance of 3½ miles to the filtration works and main pumping station at Ditton through two means of communication: (1) A brick conduit of oval shape, 5 feet 9 inches high and 4 feet 9 inches wide, with intervals of cast-iron pipes 54 inches in diameter, and (2) an iron pipe 36 inches in diameter. There is also an intake at Ditton, but this is only used when, from special causes, the intake at Molesey is not available.

**Ditton Works.**—At Ditton about one-third of the unfiltered water is delivered on to four low-level filter beds, and the remainder into a suction reservoir at the same level. Three engines, of a total capacity of 280 horse-power, lift the water from the suction reservoir into a reservoir serving eight filter beds 16 feet higher than those referred to. The two reservoirs contain together 3,000,000 gallons. There are in all twelve filter beds, containing a filtering area in the aggregate of 12½ acres. The filtering material is composed of 3 feet of washed sand and 3½ feet of fine and coarse gravel.

From Ditton the bulk of the water is pumped through three mains, each 30 inches in diameter, a distance of 10 miles into two reservoirs at Brixton, the remainder being pumped into a reservoir at Coombe through two mains, each 12 inches in diameter, which also serve as distributing mains. The reservoir at Coombe supplies by gravitation the districts of Esher and East and West Molesey through two mains, each 10 inches in diameter. Kingston is also supplied by these pumping mains. The total engine-power available at Ditton is 150 horse-power for the Coombe Reservoir, and 1660 horse-power for the reservoirs at Brixton, and 330 horse-power for Coombe and Brixton alternatively. These engines are capable of pumping, approximately, 3,000,000, 7,000,000 and 39,000,000 gallons per day respectively.

From the Brixton Works water is supplied by gravitation into the town district, the whole of which is on constant service through four trunk mains, respectively 24, 20, 18 and 12 inches in diameter, while the water for the country district is pumped from the station by ten engines of 1005 horse-power into service reservoirs, through nine trunk mains, which also serve as distributing mains. The water is distributed from these reservoirs through fifteen leading mains, varying from 10 to 18 inches in diameter.

The service reservoirs for the supply of the country district are as follows:

| Reservoirs. | Height above O. D. | Capacity in gallons. |
|---|---|---|
| Coombe (one reservoir) | 180 | 1,150,000 |
| Coombe (standpipe) | 220 | ——— |
| Brixton (two reservoirs) | 115 | 12,000 |
| Streatham (two reservoirs) | 198 | 7,500,000 |
| Selhurst (one reservoir) | 218 | 2,500,000 |
| Selhurst (standpipe) | 230 | ——— |
| Norwood (one reservoir) | 315 | 5,000,000 |
| Rock Hill (one reservoir) | 372 | 6,150,000 |
| Rock Hill (tank) | 387 | |
| Rock Hill (standpipe) | 412 | ——— |

The average quantity of water supplied in 1897 was 23,688,305 gallons daily to a population of 666,981.

## Southwark and Vauxhall Waterworks Company.

The Vauxhall Company was founded in 1805, and the Southwark Company in 1822, the two companies being amalgamated under the name of the Southwark and Vauxhall Company in 1846. The supply was originally obtained from the River Thames at Battersea, but under the Act of 1852 the intake was removed to Hampton. Under their statutory powers there is no limit to the quantity of water which the company may take from the Thames, but the amount is restricted by agreement with the Thames Conservancy to a quantity of 24,500,000 gallons through their intake at Hampton. In 1897, however, the company obtained temporary powers to take an additional quantity of 20,500,000 gallons daily from the Thames, which were made permanent by an Act passed in 1898, conditionally upon their constructing the storage reservoirs proposed under that Act, and with the restriction that the

water may only be taken from the surplus above 285,000,000 gallons flowing at Penton Hook Weir. When these works are completed the company will therefore have powers to take 45,000,000 gallons daily permanently from the Thames.

In addition to the above sources of supply the company obtained Parliamentary sanction in 1884 to purchase lands, sink wells and construct the necessary works to supply water therefrom. The first well was sunk at Streatham, and from this a quantity between 2,000,000 and 2,500,000 gallons daily has been regularly obtained since July 1, 1895. At Merton the work of sinking another well is in progress, while further wells are under contemplation.

**Districts of the Company.**—The districts supplied by the company comprise part of Southwark, portions of Lambeth and Peckham, and the whole of Battersea, and also include Ham, Pertersham, Kew, East Sheen, Sheen, Roehampton, Mortlake, Barnes, Putney and such parts of the parish of Wimbledon as are above the 100 feet ordnance contour. The company also supply Richmond to a considerable extent with water in bulk, under the agreement incorporated with the Companies Act of 1897.

**Works.**—The present works of the company are at Hampton, Battersea, Nunhead, Wandsworth, Forest Hill, Streatham, Raynes Park (site of proposed works) and Honor Oak.

**Reservoirs and Wells.**—At Hampton there are three storage reservoirs with a total capacity of 390,000,000 gallons. The company also possess natural filtration works in the gravel at this station with an area of 39¾ acres. The number of filters in use is nine, having an area of 9¼ acres; an additional area of about 7 acres will probably be completed during the present year. The filtering material consists of 3 feet of sand, 1 foot of hoggin, 9 inches of fine gravel and 9 inches of coarse gravel.

Engines with 26,000,000 gallons daily capacity pump the water to Nunhead or into the district, engines, in duplicate, of 16,000,000 gallons capacity lift the water obtained from the natural filtration works, two pairs of single-acting quadruple-expansion high-speed engines, driving centrifugal pumps with 20,000,000 gallons daily capacity, raise water from the river to fill the reservoirs, and three inverted direct-acting Cornish engines of the "Bull" type with 23,000,000 gallons daily capacity pump the unfiltered water to the Battersea Works.

Three sets of triple-expansion rotative pumping engines, with direct-acting pumps, are now in course of erection.

**Battersea Works.**—The unfiltered water delivered by the 36-inch main from the intake of the works at Hampton is received at Battersea into three reservoirs, having a total capacity of 46,000,000 gallons, passes through the filters, of which there are 11¼ acres, and is distributed by six Cornish engines, having a total capacity of 31,500,000 gallons daily.

**Nunhead.**—The works at Nunhead consist of four reservoirs, two with a top-water level of 168 feet above O. D., each having a capacity of 6,000,000

gallons, and two with a top-water level of 200 feet above O. D., each having a capacity of 3,000,000 gallons. Those reservoirs supply by gravitation a portion of the eastern part of the district, and also a portion of the Peckham and Dulwich Districts. The engines are single-acting, of the Cornish type, of 7,000,000 gallons capacity per day. A preliminary boring has been sunk at these works, which struck the chalk at a depth of 167 feet.

**Wandsworth.**—The works at Wandsworth contain two pairs of direct-acting quadruple-expansion rotative engines, capable of pumping 9,000,000 gallons daily to the high-level districts and reservoirs at Forest Hill. These engines draw their supply from the 30-inch main from Hampton.

**Forest Hill.**—At Forest Hill there are two reservoirs, each having a capacity of 500,000 gallons with a top-water level of 140 feet above O. D.

**Streatham.**—The works at Streatham consist of two pairs of three-cylinder triple-expansion engines, with lift and pressure pumps, delivering about 2,500,000 gallons daily against a head of 200 feet.

The average daily supply of the company in 1898 was 32,743,058 gallons; the estimated average population was 816,894.

## Kent Waterworks Company.

The company, incorporated by special Act in 1809, and extended under subsequent Acts of 1811, 1852, 1864, 1877 and 1888, now supply water within an area of 178 square miles, comprising many rural districts in Kent.

The population supplied was estimated to be, at the end of 1897, 519,340, the number of supplies being 86,390. The average day's quantity supplied in 1897 was 15,482,053 gallons, or at the rate of 29¾ gallons per head of the population. About 93½ per cent. of the supplies are on the constant service.

**Sources of Supply.**—The supply of water throughout the company's area is obtained entirely, with one exception, from the chalk strata between the North Downs and the Thames by means of deep wells and borings, situated as follows:

| Where Situated. | Wells. |
|---|---|
| Deptford (chalk) | 3 |
| Plumstead " | 1 |
| Crayford " | 3 |
| Shortlands " | 2 |
| Farnborough (chalk) | 2 |
| Wilmington " | 2 |
| Westerham (green sand) | 1 |

A second well has been sunk in the chalk at the Wilmington pumping station, largely augmenting the yield of water there. The company are now sinking, and have nearly completed, another well in the chalk, in the parish of Southfleet, near Gravesend, and a second well, also in the chalk, at Kent Gate, in the parish of West Wickham. The pumping stations are eight in number, situated on the sites of the wells. At Deptford there are six pumping engines, with a total capacity of 25,170,000 gallons in twenty-four hours, supplying reservoirs at Deptford, New Cross, Greenwich Park and Woolwich Common. At Plumstead a rotative pumping engine will pump 1,296,000 gallons in twenty-four hours, supplying reservoirs at Plumstead Common.

At Shortlands are two Cornish engines, with a total capacity of 2,750,000 gallons daily, supplying Chislehurst. At Crayford, three pumping engines, with a total capacity of 4,500,000 gallons, supply Woolwich Common and Eltham. At Dover Road a pair of horizontal rotative engines can pump 364,000 gallons in twenty-four hours for the extra lift to Shooter's Hill. At Farnborough are four pumping engines, with a total capacity of about 5,128,000 gallons in twenty-four hours, supplying Farnborough, Knockholt, Constitution Hill and West Wickham. At Wilmington a pair of compound rotative pumping engines, with lift and force pumps, can deliver 8,000,000 gallons daily to Eltham. At Westerham there is a waterwheel with pump which supplies 250,000 gallons daily at Westerham.

## Staines Reservoirs Works.

The evidence given before Lord Balfour's commission in 1892 showed that whereas an average daily flow of 1,350,000,000 gallons was passing down the river, only 90,000,000 gallons were being taken for water supply. It therefore appeared that, if some of the superabundant water was stored when the river was running with a high flow, it could be used for water supply when the river was running at its minimum flow, which the Thames Conservancy consider should be 200,000,000 gallons daily at Teddington Weir. The question was carefully taken up, and a report presented to the Royal Commission, who approved the scheme. Difficulties arose in regard to its execution, but eventually in 1895 the New River Company, West Middlesex Company and Grand Junction Company instructed their engineers to prepare a scheme for Parliament. Certain modifications in the design of the works were suggested. The Staines Reservoirs Act was passed in the session of 1896. By it a joint committee, consisting of nine members—three from each company—was constituted, with powers to carry out the works, which are now being constructed to the designs and under the superintendence of Mr. Middleton.

The works consist of two large reservoirs, having a total capacity of 3,300,000,000 gallons, situated about half a mile to the northeast of the town of Staines. The intake from the Thames is situated on the Middlesex bank of the river, about 300 yards above Bell Weir. At this point sluices and a sluice house are being constructed, the intake being protected by screens. The first length of the conduit for about 350 yards is covered, but after passing the Colne Brook it continues as an open conduit to the engine house, up

to which point it has a capacity of 147,000,000 gallons daily, with a fall of about 9 inches per mile. The pumping machinery will consist of five triple-expansion surface-condensing Worthington pumping engines—one being a spare engine, each capable of delivering 16,000,000 gallons daily into the reservoirs. The steam will be provided by six Babcock & Wilcox boilers—one a spare boiler—the working pressure being 150 pounds per square inch. The water will be delivered into the reservoirs through two riveted steel mains, each 6 feet 3 inches in diameter, joining into a steel pipe 8 feet 8 inches internal diameter, near the reservoirs, from which branch pipes of the same diameter will be taken down through a tunnel constructed in the clay, and connected to the water tower near the corner of each reservoir, where the western and central embankments join. The tunnels and water-towers will be constructed of Portland cement concrete; the former lined and the latter faced with blue bricks. The standpipes for discharging water from the reservoirs will be of cast iron, 5 feet internal diameter, having 48-inch and 36-inch sluice valves to enable the water to be drawn off at any desired level. From the bottom of each standpipe a cast-iron pipe, 4 feet in diameter, will convey the water through the tunnel and across the New Stanwell Road to a basin 50 feet in diameter, in which a weir will be constructed for the purpose of aëration, and over which the water will be delivered into the conduit, which will rejoin the main conduit a little to the east of the pumping station. The reservoirs are being constructed with earthen banks, excavated from the interior area of the reservoirs. In the center of these banks a puddle wall is being constructed down into the solid clay, thus forming a perfectly tight reservoir. The clay for the puddle wall is being excavated within the area of the reservoirs below the top stratum of gravel, which varies from 14 feet to 35 feet in thickness.

From the engine house the conduit reduced in section leads to the back of the East London Waterworks at Hanworth, at which point it will deliver water to the new works of the New River Company, and finishes in a reservoir of 30,000,000 gallons capacity at Hampton, whence the water will be delivered into the works of the West Middlesex and Grand Junction Companies.

Under the Staines Reservoirs Act the Joint Committee has power to supply 35,000,000 gallons daily to the Joint Companies, or 45,000,000 gallons daily under emergency by consent of the Local Government Board. The maximum quantity allowed to be taken from the river for supply and for filling the reservoirs is restricted to 100,000,000 gallons in 24 hours, but this quantity must be taken out of the surplus water above a flow of 265,000,000 gallons daily at Bell Weir.

## Southwark and Vauxhall Company's Storage Scheme.

Under this Company's Act of 1898, the Company is about to construct at Molesey, under the advice of their engineer, Mr. Restler, storage reservoirs of 1,070,000,000 gallons capacity, which, when completed, will give them the right to take the additional quantity of 20,500,000 gallons from the river before referred to.

TOTAL SUPPLY AUTHORIZED FROM THE THAMES.

From the foregoing descriptions it will be seen that the total quantities of water which the companies have power to take daily from the Thames upon the completion of the storage works now being constructed are as follows:

| Companies. | | Million Gallons Daily. |
|---|---|---|
| Chelsea Company | | 22 |
| East London Company | | 10 |
| Grand Junction Company | | 24.5 |
| Lambeth Company | | 24.5 |
| Southwark and Vauxhall Company | 24.5 | 45 |
| Ditto under storage scheme | 20.5 | |
| West Middlesex Company | | 24.5 |
| Staines Reservoirs Joint Committee | | 35 |
| Total | | 185.5 |

STORAGE FOR THE RIVER LEA.

The East London Waterworks Company have, under the advice of their engineer, Mr. Bryan, constructed large additional reservoirs and have deposited a bill seeking powers for still larger works, which, it is hoped, will be passed in the present Parliamentary session.

| | |
|---|---|
| Total number of supplies December, 1898 | 871,949 |
| Miles of water pipes | 5,254¼ |
| Total horse-power | 26,723 |
| Area of filtration (acres) | 129½ |

5. THE QUALITY OF THE WATER.

From the foregoing description of the companies' works it will be gathered that the purification of the water supply to London is effected by sedimentation and by sand filtration. The question whether the present supply was adequate in quality was definitely referred to Lord Balfour's Commission, which gave a verdict upon this issue in the following terms:

"We are strongly of opinion that the water, as supplied to the consumers of London, is of a very high standard of excellence and purity, and that it is suitable in quality for all household purposes. We are well aware that a certain prejudice exists against the use of drinking-water derived from the Thames and the Lea, because these rivers are liable to pollution,

however perfect the subsequent purification, even by natural and artificial means, may be; but having regard to the experience of London during the last thirty years and to the evidence given to us on the subject we do not believe that any danger exists of the spread of disease by the use of this water, provided that there is adequate storage and that the water is efficiently filtered before delivery to the consumers."

The water supplied by the companies is daily analyzed and bacterially examined on behalf of the companies by two eminent chemists, Sir W. Crooks, F.R.S., and Professor Dewar, F.R.S. Analyses are also made on behalf of the Local Government Board by Sir E. Frankland, F.R.S., who, at the request of the Associated Metropolitan Waterworks Companies, extends his examination to the chemical and bacterioscopic condition of the raw river waters at the intakes of the various companies and to the bacteriology of the water as it issues from the filter beds.

In regard to the results of the chemical analysis and of the physical and bacterioscopic examination of the water supplied during the year 1897, Sir E. Frankland reported as follows, under the date of January 31, 1898:

"In the following table are recorded the results of observations respecting the freedom from turbidity or otherwise of the various waters, and, for the purpose of comparison, the results of my first observations in 1868 are also included:

| Companies. | Number of Occasions when | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Clear and Transpar't. | | Slightly Turbid. | | Turbid. | | Very Turbid. | |
| | 1868. | 1897. | 1868. | 1897. | 1868. | 1897. | 1868. | 1897. |
| Thames— | | | | | | | | |
| Chelsea | 7 | 12 | 2 | 0 | 1 | 0 | 2 | 0 |
| West Middlesex | 12 | 12 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southwark | 1 | 12 | 5 | 0 | 4 | 0 | 2 | 0 |
| Grand Junction | 9 | 12 | 2 | 0 | 1 | 0 | 0 | 0 |
| Lambeth | 6 | 12 | 1 | 0 | 2 | 0 | 3 | 0 |
| Lea— | | | | | | | | |
| New River | 10 | 12 | 2 | 0 | 0 | 0 | 0 | 0 |
| East London | 3 | 12 | 8 | 8 | 1 | 0 | 0 | 0 |
| Deep Wells— | | | | | | | | |
| Kent | 8 | 12 | 3 | 0 | 1 | 0 | 0 | 0 |
| Colne Valley | .. | 11 | .. | 1 | .. | 0 | .. | 0 |
| East London | .. | 4 | .. | 8 | .. | 0 | .. | 0 |

"This table strikingly exhibits the great improvement which the water companies who draw their supplies from rivers have effected in filtration since I first began these examinations for turbidity in 1868. In that year seven samples were so turbid as to be highly repulsive in appearance, nine were turbid, and no less than twenty slightly turbid; whereas during **the year 1897 no sample of filtered water was turbid in the slightest degree.** On the other hand, nine samples of deep-well water, which does not usually require filtration, were slightly turbid, owing, in all probability, to disturbance by the pumping machinery.

"The purest water in nature contains abundance of suspended matter—indeed, the beautiful blue color of the purest Swiss lakes and of the Mediterranean is due to these very fine suspended matters, which require years to subside, and which no sand filter will remove, but which may be extracted in the chemist's laboratory to some extent, though not completely, by filtration through specially prepared paper. This fine suspended matter, which is, of course, always present in the most efficiently filtered London waters, is, under all ordinary circumstances, absolutely invisible to the eye. The water is clear, bright and transparent, but if a decanter of it be placed in a dark room and a ray of sunlight or electric light allowed to fall upon it the water will be seen to be full of suspended particles, which no sand or other practical filter is capable of removing, but which are partially arrested by a hard paper filter supported by a glass funnel. The amount of this suspended matter in the efficiently filtered river water supplied to the metropolis rarely, if ever, exceeds 0.0002 grain in a tumblerfull; and, therefore, in order to imbibe a single grain it would be necessary for the consumer to drink no less than 5000 tumblers full of water. Such excessively minute quantities of matter, which is presumably harmless, may safely be neglected—indeed, it is impossible, practically, to obtain water free from it."

In regard to the bacterioscopic examination, Sir E. Frankland wrote in the same report:

"The standard of 100 microbes per cubic centimetre, as an indication of efficient bacterial filtration, adopted by Dr. Koch and myself, is, of course, purely arbitrary. I consider it is a sufficient but not unduly severe test to apply to the filtration of the river-derived supplies of the London water companies, but I desire it to be distinctly understood that the infraction of this standard does not throw suspicion upon the wholesomeness of the water."

Sir E. Frankland further wrote in the second report:

"These results of the bacterioscopic examination of the unfiltered water used by the metropolitan companies are very instructive; they again show the remarkable effect of storage in reducing the number of bacteria. Thus, in March last, whilst the Thames at the intakes of the companies drawing their supplies from that river contained 50,560 microbes per cubic centimetre, the Chelsea Company, with ten days' storage, were supplying their filters with water containing only 580 microbes in the same volume. Again, in February, the East London Company, with twenty days' storage,

kept the number down to 1,050 per cubic centimetre, although 44,600 per cubic centimetre were passing the intake at Angel Road."

In the same report Sir E. Frankland gave the following particulars of the bacterial condition of the water issuing from the filtering beds of the various metropolitan companies, during the year 1897, compared with the raw material dealt with by these companies:

| Company. | Average percentage of microbes removed. |
|---|---|
| Chelsea | 98.96 |
| East London | 99.24 |
| Grand Junction | 98.46 |
| Lambeth | 99.50 |
| New River | 99.09 |
| Southwark and Vauxhall | 97.72 |
| West Middlesex | 99.40 |

The reports of Sir W. Crookes and Professor Dewar as to the quality of the water are equally satisfactory, and it is interesting to note the following extracts from their report of October 14th, 1897:

"In order to prevent any misapprehension in the public mind with regard to our monthly report on the quality of the London water, it may be advisable to repeat that the water companies in no way interfere with our position as absolutely independent scientific authorities. Further, they have no information antecedent to publication as to what will appear in our report. Our communications with the companies are chiefly confined to calling their immediate attention to the least anomaly appearing in the character or the quality of the filtered water, our chief aim being to advise the engineers of the works as to the efficiency of storage and filtration.

"**There is no city in the world where such minute and incessant care is taken daily and almost hourly to detect and report on the slightest deviation from the purity of its water supply.** Apart from the daily bacteriological examination of the clear-water wells of the company, we frequently make specific tests for the presence of pathogenic organisms. If any other than a negative result had been obtained, the fact would have been recorded."

It will, no doubt, be conceded that the above reports are eminently satisfactory.

But the strongest practical proof of the excellence of the London water supply is to be found in the record of the Vital Statistics of the Metropolis.

It will be conceded that no large city would have a death-rate of 18.2 (the death-rate of London for 1897) unless it possessed a water supply of excellent quality.

Before proceeding to the last head of this report, it is desirable to mention that a comparison between the cost of the water supply in London (a comparison worked out for a number of towns by Dr. Powle, Mr. Asquith and Mr. Alexander) as compared with the charge made in Liverpool, Manchester, Sawford, Birkenhead, Brighton, Bolton, Bristol, Derby, Oldham, Stockton and Newcastle, shows results which are very clearly stated by Mr. Arthur Shadwell in his recently-issued book upon the London water supply, in which he writes as follows:

"The highest charge in London on the 10 per cent. valuation, that of the Lambeth Company, is appreciably lower than the provincial average, and the London average is no less than 40 per cent. lower. On the £20 valuation it is 32 per cent. lower, on the £30 valuation it is 26 per cent. lower, and on the £50 valuation 11 per cent. lower; only when we come to premises rated at £100 and upwards are the London charges higher than the provincial average. In other words, by the system of graduated water rates imposed by the London companies the rich pay for the poor. This is notably the case with two companies who supply the great area of poverty, namely, the East London and the Southwark and Vauxhall. In fact, these two companies, and especially the East London, supply their poorest customers at a loss, which is made good by the higher charges on the more heavily rated houses. Under municipal authority the rates would necessarily be equalized, and the poor would have to forego the advantage they now enjoy. This fact, which is studiously kept out of sight by progressive politicians, is worthy the attention of the poorer classes, in whose interests municipalization is ostensibly advocated."

### 6. THE SUPPLY IN THE FUTURE.

Soon after the first London County Council was constituted, in 1889, it appointed a committee to consider the question of London water supply. After some inquiries and other proceedings the Council requested the Government to issue a royal commission to inquire into the London water supply. Eventually a commission was appointed, in March, 1892, consisting of Lord Balfour, of Burleigh, chairman; Sir George B. Bruce, civil engineer; Sir A. Geikie, director-general of the Geological Survey; Professor Dewar; Mr. T. H. Hill and Mr. J. Mansergh, both engineers of large experience in connection with water supply, and Dr. W. Ogle. The commissioners subsequently appointed Mr. R. E. Middleton, M. Inst. C. E., as an assistant commissioner, for the purpose of making investigation into doubtful questions raised in the course of inquiry. The terms of reference were as follows:

"Whether, taking into consideration the growth of the population of the metropolis and the districts within the limits of the metropolitan waterworks companies, and also the needs of the localities not supplied by any

metropolitan companies, but within the watersheds of the Thames and the Lea, the present sources of supply of these companies are adequate in quantity and quality, and, if inadequate, whether such supply as may be required can be obtained within the watersheds referred to, having due regard to the claims of the districts outside the metropolis, but within those watersheds, or will have to be obtained outside the watersheds of the Thames and the Lea."

Anyone reading this reference must see that four distinct issues were raised—

1. Whether the present sources of supply are adequate in quantity.
2. Whether they are adequate in quality.
3. Whether such supply as may be required can be obtained within the watersheds referred to; or,
4. Whether it will have to be obtained outside the watersheds of the Thames and the Lea.

The commission sat forty-five days and took evidence from ninety-two witnesses, including the engineers and other officials of the County Council and the water companies. The conservators of the Rivers Thames and Lea gave records of the flow of these rivers. The rainfall was treated by Mr. C. J. Symonds, F. R. S., and other meteorologists. Independent engineering and geological evidence was given by Sir F. Bramwell, Mr. T. Hawksley, Mr. Deacon, Professor Boyd-Dawkins and Mr. W. Whittaker.

Upon the question of quality, evidence was given by Sir E. Frankland, Sir W. Crookes, Dr. Odling, Dr. R. Lankester, Dr. Klein, Dr. Sims Woodhead and others.

The commission took into their purview the period of forty years, and basing their estimate upon the decennial increase between 1881 and 1891, arrived at an aggregate of the population in 1931 of 11,250,000 in the area, the water requirements of which were to be considered, viz., 845 square miles.

Taking the needs of this population at 35 gallons per head per day, the average daily quantity required in 1931 was found by the commission (paragraph 70) to be 391,717,690 gallons. Adding 6 per cent. to provide for increased demand in hot weather and in times of frost, the commissioners estimated the maximum daily provision required in 1931 at 415,219,752 gallons.

To meet this demand the commission arrived at the conclusion that if adequate storage were provided for the Thames and Lea, the following quantity of water would be available:

| Source. | Gallons per day. |
|---|---|
| From the River Thames | 300,000,000 |
| From the River Lea | 30,500,000 |
| From wells in the Lea Valley | 40,000,000 |
| From the Kent Company's district | 27,500,000 |
| Total | 398,000,000 |

Sufficient, at 35 gallons per head per day, for a population of 12,000,000.

The above figures, adduced by the commission, show, in reply to the first and third heads of reference, that the present sources of supply are adequate in quantity, and that such supply as may be required can be obtained within the watershed for the Thames and Lea. We have already dealt with the issue raised under the second head of reference, and have shown the findings of the commission to be that the water supply is "of a very high standard of excellence and purity, and that it is suitable in quality for all domestic purposes."

Inquiry into the fourth head of reference was rendered unnecessary because the commission had found that sufficient water could be obtained from the present sources of supply to cover the requirements of London for the forty years which they took into consideration.

It might have been expected, after the valuable and exhaustive report of Lord Balfour's commission, that the question of the London water supply might have been allowed to follow the recommendations of the commission for many years to come. Such, however, was not the opinion of the County Council. They had asked for the commission, apparently, in the hope and expectation that they would curse the companies, and, "Behold, they had blessed them altogether."

In 1894 the Council instructed their engineer to report "on the site and yield of other sources of water supply, and as to the method which might be adopted for considering and supplying water to London, with estimates of cost." Sir Alexander Binnie's report, dated June 8, 1894, describes a scheme for constructing large storage reservoirs for impounding the waters of the rivers Usk and Wye, and several tributaries, and bringing the water so collected to London by two aqueducts about 160 miles in length. The quantity of water to be provided from a catchment area of 488 square miles, with a rainfall varying from 45 to 70 inches per annum, was 415,000,000 gallons daily, to be delivered into reservoirs at Elstree and Banstead, at a total cost of $193,860,000. Sir Alexander Binnie proposed to construct the works in two instalments: the first to bring 182,000,000 gallons daily to Elstree at a cost of $87,500,000, to be supplemented by the Edw with 18,000,000 gallons additional, or a total of 200,000,000 gallons daily, at a cost of $90,475,000; the second instalment, to be made at a later date, would complete the total supply of 415,000,000 gallons daily at a total cost of $193,860,000, as before stated. If to this quantity be added 67,000,000 gallons daily available water from chalk wells near London, a total supply of 482,000,000 gallons daily would be obtained, sufficient for the wants of a population of 13,800,000, or down to the year 1943.

Fortified with this report, the County Council have opposed all legislation based upon the report of Lord Balfour's commission. Their opposition had previously caused the defeat of the East London Company's bill of 1893, and by postponing works which the engineer of that company declared to be necessary, had directly contributed to the scarcity of water in East London in 1895 and 1896. The Council have since opposed storage schemes brought

in by the separate companies, the Staines Reservoir Companies promoted by the West Middlesex, Grand Junction and the New River Companies in 1896, and the storage reservoirs proposed by the Southwark and Vauxhall Company in 1898. These schemes have, however, received Parliamentary sanction. The County Council have, moreover, opposed before the present Royal Commission the scheme brought forward to safeguard the supply of every district of the metropolis by making suitable connections between the works of the companies.

In 1897, the Government constituted a Royal Commission, with Lord Llandaff as chairman, to inquire "whether it is desirable, in the interests of the rate-payers and water-consumers in the districts of supply of the metropolitan water companies, that the companies shall be acquired and managed either (a) by one authority or (b) by several authorities, and, if so, what should be such authority or authorities," and other subsidiary questions.

This reference has indirectly raised the question, whether the policy of the County Council to bring water from Wales, or that of the companies to develop the present sources of supply, is the more advantageous to the rate-payers and consumers.

Notwithstanding the fact that the question of the metropolitan supply was being considered by the commission, the County Council have endeavored to forestall any recommendations which it may make by promoting bills in Parliament for the purchase of the companies' undertakings, and for carrying out the first portion of their Welsh scheme, as proposed by Sir Alexander Binnie, but slightly modified in accordance with the suggestions made by Sir B. Baker and Mr. Deacon in a report which they have given to the Council upon a reference made to them. Judging by this report and by the evidence given before the Royal Commission, the County Council appear to have abandoned their original statement, that London water is clarified sewage, unfit for potable purposes, as they are content to accept as a permanent supply the 185,500,000 gallons daily, which the companies now have powers to take from the Thames.

Now, in considering the policies of the County Council and of the companies, it must be remembered—

First, that, as previously shown, the water, as supplied to London, is "of a very high standard of excellence and purity, and suitable in quality for all household purposes."

Further, the late Mr. Hawksley showed from the health statistics of many towns in England that those which are supplied by river water are generally more healthy than those supplied from a mountain source.

That, secondly, it must also be remembered that the total supply to be obtained under the Welsh scheme is 415,000,000 gallons daily, which upon the usual proportion would give about 553,000,000 gallons daily as the total yield of the reservoirs.

On the other hand, the Thames possesses an average flow of 1,300,000,000 gallons daily upon a cycle of years.

It seems absurd, therefore, to leave a larger and equally good supply,

obtainable close to London, for another supply from a distant source, unless and until the expense of developing the larger becomes greater than that which would be incurred in utilizing the smaller and distant supply. For see what would happen. After exhausting the capacity of the Welsh supply it would be necessary to revert to the present sources, which the promoters of the distant scheme now affect to despise.

The question, therefore, resolves itself into the comparative cost of the two schemes.

In making the comparison between the cost of these schemes, it has been endeavored to hold the balance equally and fairly between them, the result being shown in the following table:

SUMMARY OF COST OF WELSH AND THAMES SCHEMES AT 1916, 1920 AND 1936, THE DATES AT WHICH FURTHER SUPPLIES WILL BE REQUIRED.

**Welsh Scheme.**—By analogy from cost of Thirlmere, Vyrnwy and Elan Valley Works—

| | Daily supply. Million gals. | Cost of works. | Interest during construction. | Capitalized pumping charges. | Total. |
|---|---|---|---|---|---|
| 1st quantity (1916 or 1920) | 121 | $103,000,000 | $15,950,000 | $435,000 | $119,385,000 |
| 2d quantity (1936) . . . | 93 | 60,555,000 | 5,450,000 | 425,000 | 66,430,000 |
| | | $163,555,000 | $21,400,000 | $860,000 | $185,815,000 |

**Thames Scheme.**—Under conditions of 1898, minimum flow 100 million gallons at Teddington—

| | Daily supply. Million gals. | Cost of works. | Interest during construction. | Capitalized pumping charges. | Total. |
|---|---|---|---|---|---|
| First quantity (1920) | 121.5 | $22,415,000 | $2,795,000 | $14,960,000 | $40,170,000 |
| Second quantity (1936) | 93.0 | 21,545,000 | 2,725,000 | 13,050,000 | 37,320,000 |
| | | $43,960,000 | $5,520,000 | $28,010,000 | $77,490,000 |

**Thames Scheme.**—Under conditions of 1898, minimum flow 200 million gallons at Teddington—

| | Daily supply. Million gals. | Cost of works. | Interest during construction. | Capitalized pumping charges. | Total. |
|---|---|---|---|---|---|
| First quantity (1916) | 121.5 | $33,865,000 | $7,020,000 | $13,705,000 | $54,590,000 |
| Second quantity (1936) | 93.0 | 25,195,000 | 3,160,000 | 13,400,000 | 41,755,000 |
| | | $59,050,000 | $10,180,000 | $27,105,000 | $96,345,000 |

**Thames Scheme.**—Under conditions of 1893, minimum flow 200 million gallons at Teddington—

| | Daily supply. Million gals. | Cost of works. | Interest during construction. | Capitalized pumping charges. | Total. |
|---|---|---|---|---|---|
| First quantity (1916) | 121.5 | $26,700,000 | $4,715,000 | $13,660,000 | $45,075,000 |
| Second quantity (1936) | 93.0 | 26,240,000 | 3,370,000 | 13,435,000 | 43,045,000 |
| | | $52,940,000 | $8,085,000 | $27,095,000 | $88,120,000 |

It is fair to say that the Thames estimate, and under the conditions of 1898, would be slightly increased, as the estimates were made in November, and would in no way alter the estimate under the conditions of 1893.

It will be seen from the above table that the cost of the Welsh scheme for the supply of the same quantities of 121.5 and 93,000,000 gallons daily will be in round figures from two to two and one-half times the cost of the supply of the same quantity by the Thames scheme, dependent upon the minimum flow fixed at Teddington.

The above quantities, added to the 185,500,000 gallons already authorized, provided for a total quantity of 400,000,000 gallons daily being taken from the Thames, sufficient with the water available from the Lea and wells in the chalk for the supply of the metropolis to the year 1948, supposing that the population should in the meantime increase in accordance with the figures accepted by the Balfour commission. There will, therefore, be no necessity even to consider any question of increased draught from the Thames or the provision of water from an outside source, for at any rate the next forty years.

It is possible, and indeed probable, as has already happened, that the population will not increase in anything like the same rate as in the decade from 1881 to 1891. The adaptability of the Thames scheme to meet such a contingency is one of its most valuable features. The storage reservoirs contemplated under it need only be constructed as the actual increase in the population renders them necessary. Should the population increase at a slower rate than estimated, the work could be retarded until they are actually required. On the other hand, the larger part of the expenditure upon a supply from distant sources must be incurred at the outset, and may eventually be found to have been undertaken upon too large a scale, laying unnecessary financial burdens upon the rate-payers and water-consumers.

## LIVERPOOL.

The city of Liverpool stands partly on level ground along the Mersey, and partly on a gentle slope. The population is about 550,000.

The town owes its chief importance to its great foreign trade; it is the main outlet for the manufactures of Lancashire, West Yorkshire and Staffordshire, and monopolizes the principal share of British trade with Australia, America, India, Africa and the Mediterranean. The construction of large merchant and war vessels is extensively carried on; there are also large engine cable and anchor factories, iron and brass foundries, sugar refineries, breweries, glass-staining works, etc.

### Liverpool Corporation Waterworks.

**Control of System.**—The system is under municipal control. The waterworks were acquired by the corporation in the year 1847 from two private companies.

The revenue required to pay interest on capital and working expenses is obtained—

1. By a fixed public water rate of 6d. in the £ levied upon the rateable value of all property (poor rate assessment) in the city.

2. By revenue derived from trade supplies through meter and miscellaneous charges.

3. By a domestic water rent charged upon the rateable value of premises receiving a domestic supply. This water rent is fixed at an amount sufficient to raise the total revenue required for the undertaking after allowing for the yield of the fixed water rate and charges for trade supplies. The corporation are not allowed to make any profit on the undertaking.

**Total Daily Consumption.**—The total daily consumption during the year ending December 31, 1897, was as follows:

Maximum, 29,986,000 British gallons.
Minimum, 15,100,000 British gallons.
Average per day, 22,954,000 British gallons.

The gravitation water is measured over notch gauges at the entrance to the aqueducts and also before distribution near Liverpool.

**Sources of Supply.**—Of the average quantity per day given above 4,007,000 gallons were obtained from wells sunk in the new red sandstone formation in the neighborhood of Liverpool, 10,132,000 gallons from Rivington Gravitation Works, and 8,815,000 gallons from Vyrnwy Gravitation Works.

The Rivington supply is obtained from an upland district on the millstone grit formation in Lancashire, distant about 30 miles from Liverpool.

The Vyrnwy supply is obtained from the upper waters of the River Vyrnwy in North Wales, distant 78 miles from Liverpool, along the Aqueduct.

**Storage Reservoirs.**—The Rivington Reservoirs have been formed by earth embankments with clay puddle core walls. The area covered by these reservoirs, including filter beds, is 615 acres, containing altogether 4,107,000,000 gallons, and the greatest depth varies from 78 to 93 feet. The length is 3½ miles and the average width at bottom 21 feet. In ordinary work they will filter 15,000,000 gallons daily.

Lake Vyrnwy is situated in the parish of Llanwddyn, in the county of Montgomery, in North Wales.

It lies in a remote and unfrequented part of the principality, and there is neither railway station nor railway line within less than ten miles.

**General Dimensions.**—When the lake is full to the overflow the surface of the water is 825 feet above the sea (ordnance datum), and the principal dimensions are—

| | |
|---|---|
| Superficial area | 1121 acres. |
| Length | 4¾ miles. |
| Average width | ½ mile. |
| Greatest depth | 84 feet. |
| Contents in gallons | 13,125,000,000. |
| Contents in cubic feet | 2,103,000,000. |
| Contents in tons of water | 58,000,000. |

The length of the road around the margin of the lake is 11¾ miles, exclusive of the road over the dam.

**Gathering Ground and Yield.**—The area of the gathering ground from which water is collected is 18,000 acres; but the corporation have power to divert two neighboring streams—the Cowny and the Marchnant, with a gathering ground of 5200 acres—so that when all the works contemplated by the Act of 1880 have been carried out the lake will have a total watershed of 23,200 acres; and it is estimated that the rainfall on this area will yield an average daily supply of about 53,000,000 gallons, of which 40,000,000 gallons will be available for Liverpool, after delivering compensation water to the river, as provided by the Act of Parliament.

**The Dam.**—The dimensions of the wall are as follows:

Total length along the top, 1165 feet.

Height from lowest part of the foundation to parapet of carriageway, 161 feet.

Height from river bed to sill of overflow (under the roadway), 84 feet.

Greatest thickness at base, 120 feet.

Width of roadway over top of dam (between the parapets), 19 feet 10 inches.

The batter or slope of the wall on front or water side is 1 horizontal in 7¼ vertical.

The slope of the back of the wall is 1 horizontal in 1½ vertical.

The total quantity of masonry in the dam is 260,975 cubic yards.

The total weight of the masonry is 510,000 tons.

The quantity of earth and stones that had to be excavated for the foundations was 220,890 cubic yards.

The refilling at the front and back of the wall amounted to 79,501 cubic yards.

The cost of the masonry has been $2,650,000, and the total cost of the dam $3,005,000.

**Construction.**—It has been built of a hard, slaty, dark-gray stone, difficult and expensive to manipulate, belonging to the Caradoc group of the Lower Silurian system, and obtained from a quarry distant 1¼ miles to the north. The masonry is of the kind known as coarse rubble, and from the unusually large size of the blocks used it has been described as "cyclopean" rubble. Some of the stones have weighed ten tons, and more than one-third of the stones in the dam have exceeded four tons each. The stone weighs 2.06 tons per cubic yard. Every large stone was worked on the underside to a flat surface and set in Portland cement mortar of exceptional strength. Interstices between the irregular sides and ends were filled in with Portland concrete, rammed so as to produce an unbroken and well-consolidated mass. Samples of this concrete have been tested and give an average resistance to crushing of 293 tons per square foot. The face stones are all draughted to templates, and have their upper and lower sides dressed parallel. All the stones in the dam, including the ashlar in the discharge-tunnel outlets, were obtained from the same quarry and carried in wagons on a railway laid down for the purpose.

**Overflow.**—A special feature of this dam is the overflow. Instead of constructing an independent bywash or waste weir in the hillside, as is ordinarily done at the end of a reservoir embankment, the top of the dam itself, in this case, is utilized for passing over the surplus waters, and when the lake is full a flood flows away harmlessly, but very noisily and very beautifully, through the nineteen central arches and down the back of the wall. At the outer toe a massive apron has been built to prevent damage to the foundations by falling water or ice.

**Viaduct.**—The roadway over the dam is carried on 31 elliptical arches of 24 feet span. The overflow level is 10 feet below the surface of the roadway.

**Outlet Tunnels.**—Looking down the back of the wall the outlet ends are seen of two tunnels which pass through the dam at the ground level. During the construction of the works these were used for the temporary diversion of the river, so as to keep the valley dry. They are circular, 15 feet in diameter and 70 feet in length. The passage of water through them is now effectually stopped by a thickness of 18 feet of brickwork, in which are built pipes controlled by sluice valves, which can be opened and shut by means of spindles carried up to the valve chambers above. In the northeastern tunnel there is one pipe 39 inches in diameter, and in the southwestern tunnel there are two pipes, one of 30 inches diameter and one of 18 inches diameter.

**Compensation Water.**—Through the 18-inch pipe is discharged the daily compensation water, and through the 30-inch pipe the monthly compensation water is given.

This "compensation" is the water which the corporation have to send down the river as satisfaction to the riparian owners below, and to the Severn Navigation and Fishery Commissioners, for impounding the floods of the upper Vyrnwy. And very liberal compensation it is. Before the lake was made, the flow down the Vyrnwy at this point in a dry summer did not amount to 2,000,000 gallons per day, while in wet seasons rain fell in such torrents that lands below were flooded, mill weirs swept away and crops destroyed. In place of this erratic and unreliable and unmanageable body of water, the corporation now send down a steady, constant and never-failing stream, alike in summer and winter, of 10,000,000 gallons per day. In addition to this daily, unintermittent supply, the corporation have to deliver to the river every year 1,200,000,000 gallons of water, in the form of "freshets" of 40,000,000 gallons each, as and when the Severn commissioners may require. This is a condition that was unexpectedly and unprecedently imposed when the Vyrnwy Bill was before Parliament. It has involved the raising of the dam five feet higher than was originally intended, and has, of course, added seriously to the cost. The "freshets" are supposed to be beneficial in connection with the breeding of fish and the scouring of the Severn.

**Vrynwy Tower.**—The Straining Tower stands in 50 feet depth of water. The total height of the tower is 104 feet above the surface of the lake, and the internal diameter near the base is 30 feet 6 inches. This is the entrance gate to the Liverpool Aqueduct, and it has been placed here in order that water may be drawn off free from the turbidity which the heavy floods coming down the Cynon will occasionally cause nearer to the dam.

On the southern side and outside of the tower there are two columns of pipes, each 3 feet 6 inches in diameter, so arranged that water can be drawn off for conveyance to Liverpool from any desired level of the lake. In practice it will be drawn off at a short distance below the surface at a point where the best quality is found. Through these pipes it will flow into the tower, and within the tower it will be made to pass through cylindrical

screens consisting of a strong wrought-iron frame covered with fine copper-wire gauze. There are three of these cylinders, each 9 feet in diameter by 25 feet in height, and the wire gauze has 14,400 meshes to the square inch. It is the "straining" process through this sieve that gives the name to the building. The gauze is much finer than is usually employed to remove the particles of matter, organic and inorganic, that are always held in suspension by lake waters. When these accumulations seriously impede the flow through any of the screens, the fact will be proclaimed by the ringing of a bell set in motion by the obstructed fluid. This will be a signal to the attendant to start a hydraulic engine which has been provided for the purpose of lifting the clogged screen out of the water to an upper chamber, where it will be washed by powerful jets and its full action restored. The total area of the wire gauze on the three screens is 2034 square feet. After passing through the strainers the water is received into pipes—one for each strainer—which lead to a circular culvert 4½ feet in diameter, made entirely of concrete and built in the bed of the lake below the lowest water level. This culvert is 825 yards in length and conveys the water to the Hirnant Tunnel, the mouth of which is seen on the margin of the lake near to Cynon Bridge. The hydraulic machinery in the straining tower is worked by pumps driven by water-pressure from a stream on the adjoining hillside.

### THE AQUEDUCT FROM LAKE VYRNWY TO LIVERPOOL.

**Length.**—The total length of the aqueduct from the lake to the terminus at Prescot, near Liverpool, is 68 miles.

**Construction.**—With the exception of about four miles of tunneling, the aqueduct consists of cast-iron socket pipes, varying in internal diameter from 39 to 42½ inches, and in thickness from 1 to 2¼ inches, according to the head or pressure of water they have to sustain. They are made in lengths of 12 feet each, and joined together by means of lead joints. The weight of each pipe ranges from 2½ to 5¼ tons. The quality of the iron pipes was carefully specified, and specimen bars were cast on each pipe throughout the progress of the manufacture and subjected to severe tests for transverse and tensile strength. Each pipe was also proved by closing the ends and filling it with creosote oil, under a pressure (applied by a pump) more than double that it would have to bear in actual work. After being proved every pipe was dipped into a nearly boiling preparation of asphalt and tar (Dr. Angus Smith's process) and thus coated with a hard, durable, black varnish.

**Pipe Laying.**—The pipes have been laid cross-country, in a line as nearly straight as practicable, between the balancing reservoirs, and following the undulations of the ground, so that, with a regular rising or falling gradient, the depth of cover is not less than three feet and rarely more than ten feet.

**Wash-out Valves.**—At all depressions in the line there are sluice or wash-out valves by which the aqueduct can be emptied when repairs are needed.

**Air Valves.**—At all high points, where the pipes dip to a lower level, air cocks are provided, which, by the automatic action of a float, will release any air that may collect at the top, so as to prevent the shocks and the obstruction to the flow that would be caused by such accumulations.

**Self-acting Valves.**—Attached to the outlet pipe of each balancing reservoir and at distances apart not exceeding five miles throughout the aqueduct there are large valves of ingenious construction which will close automatically if a serious leakage takes place. The action of these valves is briefly as follows: A disc is held in the center of a pipe by a lever, so weighted and balanced that when water is flowing at its normal velocity the disc remains stationary; but if a pipe bursts on the delivery side of the valve, the sudden increase of velocity ensuing pushes the disc forward, releases a trigger and sets in motion mechanism by which the valve is made to move slowly to its seating, and the passage of water is effectually stopped. The same mechanism rings a bell in the reservoir-keeper's house, thus acquainting him with the occurrence of the accident.

Similar valves have been in successful operation on the Rivington Aqueduct for over thirty years.

**Stopcocks.**—Besides the self-acting valves there are, at the balancing reservoirs and at frequent intervals along the pipe-line, stopcocks placed to enable the attendants to regulate or entirely shut off the flow through the aqueduct.

**Divisions of Aqueducts.**—For constructional reasons and for facility of management the aqueduct has been divided into six parts. At the end of each division the water is delivered into an open tank or balancing reservoir, from the bottom of which it is drawn off to resume its journey towards Liverpool. The following are the divisions:

| Divisions. | Length. Miles. | Yards. |
|---|---|---|
| 1. From Lake Vyrnwy Straining Tower to Parc Uchaf Reservoir, near Llanrhaiadr-yn-Mochnant . . . . | 9 | 1,344 |
| 2. From Parc Uchaf Reservoir to Oswestry Reservoir . . | 8 | 75 |
| 3. From Oswestry Reservoir to Malpas Tank . . . . . | 18 | 1,038 |
| 4. From Malpas Tank to Cotebrook Reservoir . . . . . | 11 | 1,009 |
| 5. From Cotebrook Reservoir to Norton Tank . . . . . | 10 | 1,693 |
| 6. From Norton Tank to Prescot Reservoir . . . . . | 9 | 750 |
| Total length to Prescot Reservoir . . . . . | 68 | 629 |

**Hirnant Tunnel.**—When the Vyrnwy scheme was conceived, one of the first questions to be considered was, how the water was to be got out of the valley after the reservoir had been built. The method ultimately chosen was to drive a tunnel from the bottom of the new lake, through the hills on the northwestern side, into the valley of the Hirnant. This tunnel is 2¼ miles long and has a total fall from end to end of 4½ feet. It has a clear internal diameter of 7 feet, and, with 40,000,000 gallons per day running through, the depth of water in it will be about 5 feet. About one-sixth of the tunnel has been lined with brickwork in Portland cement, but with this exception it is all in compact rock and without any artificial lining. The driving of the tunnel occupied three years.

**Hirnant to Parc Uchaf.**—At the outlet end of the tunnel the water is received into a chamber, from which it is conveyed down the Hirnant Valley through a cast-iron pipe of 3 feet 6 inches internal diameter, skirting the southern bank of the brook until near to the little village of Pen-y-bont-fawr, where the pipe-line crosses to the northern side, and, after passing above the village and under the River Tanat, ascends the western slope of the Tanat Valley and skirts the side of the public highway between Pen-y-bont and Llanrhaiadr. The River Rhaiadr is crossed about 300 yards above the bridge in the village. After crossing the Rhaiadr Valley the line inclines to the south and enters the watershed of the Twrch, after crossing which it rises to and terminates in the Parc Uchaf relieving tank, about 1½ miles to the east of Llanhaidr.

The pipes for this section were carted from a depot specially provided at Llanyblodwell, on the Cambian Railway, and to reach some parts of the aqueduct as many as fourteen miles of rough and hilly roads had to be traversed.

**Parc Uchaf Reservoir.**—The Parc Uchaf Balancing Reservoir is built of concrete lined with blue bricks. It holds 2,000,000 gallons. Adjoining the reservoir is a keeper's cottage.

**Parc Uchaf to Oswestry.**—From Parc Uchaf the pipe, still 42 inches diameter, is continued through the parish of Llansilin, and to the north of Llansilin village, as far as the left bank of the Cynllaith stream, about three-quarters of a mile south of Rhyd-y-croesau. Here pipe-laying is stopped by the Cynynion Hills, and it has been necessary to drive a tunnel, seven-eighths of a mile long, through to the valley of the River Morda. This pretty valley is crossed by a syphon pipe discharging into the Llanforda tunnel (nearly a mile long), which begins on the north side of the Morda Valley and ends close to Oerley Hall, Oswestry.

**Oswestry Reservoir.**—At this place advantage has been taken of a depression in the ground to form a reservoir by constructing an embankment of earth and clay about 1500 feet long. This reservoir has been made of larger capacity than the other pipe-line reservoirs, so as to provide a reserve of water near to the filter beds.

**Filter Beds.**—At a distance of nearly three-quarters of a mile from, and at a level of 130 feet below, the Oswestry Reservoir the beds for filtering the water have been placed. For the first instalment three filter beds

have been built, having a total superficial area of 24,000 yards. The filtering material consists of—

| | |
|---|---|
| Sharp, coarse, silicious sand . . . | 2 feet in depth. |
| Gravel . . . . . | 1 foot in depth. |

The unfiltered water is conveyed from the reservoir to the filter beds (or it can be sent direct from the Llanforda tunnel without entering the reservoir) through a cast-iron pipe of 42 inches internal diameter. It is delivered on to the top of the filters, and percolates slowly through the sand and gravel into drains at the bottom of the beds, whence it is collected into a filtered water-tank holding 2,812,500 gallons. From this tank the filtered water is sent forward to Liverpool as required.

**Oswestry to Malpas.**—The pipe-line proceeds on the north side of the town of Oswestry, through a corner of Lord Harlech's park, and under the Great Western Railway Company's branch, near Oldport. The pipe is carried under the railway in a brick culvert of sufficient dimensions to permit of inspection, and to enable ordinary repairs to be effected. The main line of the Great Western Railway is similarly crossed close to Whittington Station. From Whittington the pipe-line runs alongside the Whitechurch Railway to the village of Hindford. Here the Shropshire Union Canal is crossed, the pipes being laid in the bed of the canal without a subway. The aqueduct continues through New and Old Marton, Duddleston Heath, Penley and Willington, to the Wych Brook, near Dymock Mill. Under the Wych Brook the pressure on the pipes is exceptionally heavy, and steel tube has been employed instead of cast-iron. After passing through Oldcastle Heath and Mapas this division of the line ends at the balancing tank at Oat Hill, between the town of Malpas and the railway station. This is a small tank, containing 270,000 gallons, which is to form part of a future reservoir, for which land has been acquired.

**Malpas to Cotebrook.**—Between Malpas and Cotebrook the pipe-line goes through the parishes of Bunbury and Tarporley, passing close by Beeston Castle Station, and about a mile to the east of Tarporley village.

It crosses under the London and Northwestern Railway twice in brickwork subways, and under the bed of the Shropshire Union Canal in Beeston.

The Cotebrook Balancing Reservoir stands on a hill in the township of Utkington. It is built of bricks in Portland cement, and holds 2,000,000 gallons.

**Cotebrook to Norton.**—After leaving the Cotebrook Reservoir the aqueduct enters the Delamere Forest and crosses the Cheshire Lines Railway within a few yards of Delamere Station. The railway is in cutting and a wrought-iron riveted tube is carried over, at a height of 16½ feet above the rails. There are no special works in Norley and Kingsley, which are next traversed, until the pipes arrive at the River Weaver Navigation, on the extreme northern boundary of the township of Kingsley. The method of crossing this river had to be settled by an arbitrator appointed by the Board of Trade. As carried out, a trench was excavated by dredgers in the bed of

the waterway, and into this trench three lines of steel tubes, riveted, each 32 inches internal diameter, were lowered. The tubes were then covered with 18 inches of concrete.

After leaving the Weaver the pipe-line runs through Aston, near Aston Hall, and crosses under the London and Northwestern Railway, in a subway, in Sutton Weaver. Thence it rises quickly to the Norton Water Tower, a structure which had better be described in the words of the engineer who designed it (Mr. G. F. Deacon):

"The tower, of Roman Doric design, is built of the new red sandstone of the district. Its height to the top of the tank is 113 feet, its diameter at the base 95 feet. The tank is supported without girders or columns. Upon the circular cornice of the masonry rest cast-iron plates, and upon these is placed a hard steel expansion joint supporting a hoop of riveted steel plates of the same diameter as the tower, designed to resist compression toward its center. From the interior of this hoop is suspended a basin, in the form of the segment of a sphere, constructed entirely of mild steel plates. This basin, and the vertical cast-iron sides which serve to deepen it, will form the balancing reservoir, and will contain 651,000 gallons. The reservoir is connected with the pipes of the aqueduct by means of vertical pipes, provided with expansion joints where they pass into the spherical segment."

**From Norton Tower to the Mersey.**—Within less than a mile of the Norton Tower, and still within the township of Norton, the Bridgewater Canal is reached. This has been crossed without difficulty by temporarily emptying the canal and laying pipes in the bed of it. Within about half a mile of the Bridgewater Canal the pipe-line comes to the Manchester Ship Canal, as to the mode of crossing which there has been a good deal of negotiation and discussion. As eventually arranged, the Ship Canal Company has built a brick culvert at the bottom of the canal of sufficient capacity to hold the three lines of pipes for the three instalments of Vyrnwy water. Immediately after passing under the Ship Canal the River Mersey has to be crossed.

The banks of the Mersey are reached 2½ miles above Runcorn and 4 miles below Warrington, at a point locally known as Fidler's Ferry. The original intention of the engineers was that pipes should be laid in the bed of the river, but this project was opposed, and a clause was inserted in the Act of Parliament under which the Board of Trade were to determine how and at what level the river should be crossed. An inquiry was held, and the Board of Trade decided that the aqueduct should be placed at such a level that no part of it would be less than 17 feet below the level of the river. To comply with this condition it was decided to make a tunnel in the boulder clay formation, which borings had shown to exist in an apparently continuous stratum at a depth under the bottom of the river varying from 61 feet on the Cheshire side to 73 feet on the Lancashire side. Under the clay the new red sandstone was found, but to tunnel in the rock would have involved going to considerably greater depth than in the clay, and an uncertain expenditure for pumping. As designed, a shaft consisting of cast-iron rings,

having an external diameter of 10 feet 9 inches, was to be sunk on the Cheshire side to a depth of about 86 feet below the river bank, and a similar shaft on the Lancashire side to a depth of about 105 feet below the river bank. Between these two shafts a circular tunnel, 805 feet in length, was to be driven, with an outside diameter of 10 feet, and lined with cast-iron plates, made in segments, bolted together in position. In this tunnel strong steel pipes, 32 inches diameter, were to be fixed to carry the water. The contract for the work was let in April, 1888, and was to have been completed in April, 1889.

The contractors sank and lined the Cheshire shaft to the prescribed depth, and drove about 57 feet of tunnel from that side, but up to November, 1889, the shaft on the Lancashire side had only been sunk and lined to a depth of about 97½ feet from the surface. The works were then handed over by the corporation to another firm of contractors, who undertook to complete their contract by the 30th of September, 1890.

**The Mersey to Prescot.**—The cast-iron pipe aqueduct has been laid from the Lancashire bank of the Mersey through Cuerdley Marsh. Here the pipes have been carried under the L. & N. W. Railway (Garston and Warrington branch), and under the adjoining Sankey Canal. A subway encircles the pipes under the Sheffield and Midland Joint Railway in Cuerdley; also under the Cheshire Lines Railway in Barrows Green; similarly under the L. & N. W. Railway (St. Helens branch), under Bold Windmill; also under the L. & N. W. Liverpool and Manchester Railway at a short distance to the east of Rainhill Station; and, lastly, under the L. & N. W. Wigan Railway to the east of Prescot Station.

The aqueduct ends in the Prescot Reservoirs at the southeast corner of Knowsley Park. These reservoirs were constructed in the year 1855 as part of the Rivington scheme, and they hold 78,000,000 gallons.

**Composition of Lake Vyrnwy Water.**—As to the quality of the supply from Lake Vyrnwy, no analysis has recently been made, but the following copy of an estimate prepared by Professor Frankland, after analyzing many samples from the River Vyrnwy in the year 1879, will show what was expected when the scheme was adopted. For the purpose of comparison, an analysis of the Rivington water by the same eminent authority is given:

COMPOSITION OF LAKE VYRNWY WATER, WITH COMPARATIVE ANALYSIS OF RIVINGTON WATER.

| SUPPLY. | Total Solid Impurity. | Organic Carbon. | Organic Nitrogen. | Ammonia. | Nitrogen as Nitrates and Nitrites. | Total Combined Nitrogen. | Chlorine. | Total Hardness. | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|
| Vyrnwy Water—Average winter water after filtration . . . . . | 4.68 | .361 | .024 | . . | . . | . . | .74 | 2.9 | Clear and yellow. |
| Summer water after filtration . . . . . | 4.39 | .198 | .023 | .002 | . . | .025 | .77 | 2.7 | Clear and pale yellow. |
| Rivington Water . . . . . | 9.66 | .210 | .029 | .002 | . . | .031 | 1.53 | 4.0 | Clear. |

**Cost of Works.**—The cost of the works to the 31st of December, 1890, according to the last quarterly return of expenditure issued by the Water Committee, has been as follows:

| | |
|---|---|
| Masonry dam and all works in connection with the reservoir except the straining tower . . . | $3,710,000 |
| Vyrnwy Straining Tower and aqueduct from the tower to Prescot . . . . . | 4,970,000 |
| Land and easements for lake and aqueduct, Vyrnwy Estate, Hotel, etc. . . . . | 1,575,000 |
| Total . . . . . | $10,255,000 |

**Pumping Mains.**—The pumping mains range from 24 to 12 inches in diameter. They are all of cast iron, and, as they are joined to the general system of distributing mains, their lengths cannot be separately given.

DISTRIBUTING RESERVOIRS.

| Name of Reservoir. | Capacity. Gallons. | Depth. Feet. | Above Mean Sea Level. Feet. |
|---|---|---|---|
| Prescot . . . . . | 87,596,000 | 16 | 275.00 |
| Kensington . . . . . | 16,357,000 | 15 | 218.33 |
| Aubrey Street (Reservoir) . . . . . | 5,637,000 | 15 | 220.00 |
| Aubrey Street (Tank) . . . . . | 250,000 | 10 | 305.00 |
| Parkhill . . . . . | 2,100,000 | 15 | 199.83 |
| Torr Street . . . . . | 615,000 | 15 | 193.00 |
| Dudlow Lane . . . . . | 1,014,000 | 12 | 210.00 |
| Woolton Hill . . . . . | 1,164,000 | 12 | 296.91 |
| Breeze Hill . . . . . | 6,000,000 | 16 | 159.00 |

NOTE.—Principal distributing level of gravity sources 275.0 feet above O. D.

The distributing reservoirs are all built either of brickwork or concrete and are all covered with brick arches. They are all water-tight, and the supply and delivery of water are controlled by sluice valves at the intake and outlet.

**Distributing and Service Mains.**—The total length of distributing and service mains in the city and suburbs is about 900 miles, of which there are about 100 miles to which no direct connections are made for house or trade services.

These mains are all cast iron, coated with an asphaltic composition, and vary in diameter from 36 inches to 3 inches. The minimum diameter now laid in residential districts is 4 inches.

The pressure varies from about 25 pounds to 80 pounds per square inch, the average day pressure in the business part of the city being from 55 to 65 pounds per square inch.

Corrosion is prevented by the pipes being carefully dipped in the composition known as "Dr. Angus Smith's."

The joints are of the kind known as turned and bored joints.

Leakage is prevented by careful inspection of the pipes during manufacture and by testing before they are laid in the ground; also by careful pipe-laying.

**The communication pipes** between the mains and consumers' premises are laid by the corporation.

For domestic consumers no charge is made, but trade consumers are required to pay the entire cost of work. These pipes are almost invariably of lead, from ½ to 1 inch in diameter. All defects in pipes under the streets and footways are repaired by the corporation, but if in connection with trade supplies the cost is charged.

**Quality.**—The results of the last chemical analysis were as follows:

RESULT OF ANALYSES EXPRESSED IN PARTS PER 100,000.

| Description. | Total Solid Matter in Solution. | Organic Carbon. | Organic Nitrogen. | Ammonia. | Nitrogen as Nitrites and Nitrates. | Total Combined Nitrogen. | Chlorine. | Hardness. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Degrees. | Minutes. |
| Unfilter'd Rivington water . . | 10.1 | .363 | .064 | .005 | .000 | .068 | 1.5 | 3 | 38 |
| Filtered Rivington water . . . | 8.1 | .323 | .052 | .004 | .000 | .055 | 1.5 | 3 | 51 |
| Unfilt'r'd Vyrnwy water . . . . | 3.8 | .498 | .064 | .007 | .000 | .069 | 0.9 | 1 | 27 |
| Filtered Vyrnwy water . . . . | 5.2 | .313 | .041 | .003 | .000 | .044 | 0.9 | 2 | 21 |

The last bacteriological report showed—

| | Colonies per C. C. |
|---|---|
| Unfiltered water at outlet from Lake Vyrnwy to aqueduct . . . . . | 38 |
| Filtered water at Liverpool end of aqueduct . . | 6 |

All the water excepting the water pumped from deep wells is filtered before distribution.

**Consumption.**—Practically all residences and business establishments in the city are supplied by the corporation.

The average rate per head per day for all purposes is 28.73 gallons.

The maximum rate per day is about 29,986,000 gallons, and the minimum about 15,100,000 gallons.

Waste is controlled (1) by plumbing regulations, (2) by a staff of waste-water inspectors, who periodically examine all premises and repair defects. The day inspection of pipes and fittings is facilitated by the use of district waste-water meters and night inspection.

The water is constantly laid on under pressure, and no meters are used for domestic supplies. There is, therefore, no restriction upon the quantity that may be drawn.

The number of waste-water inspectors is 15 and night inspectors 2.

**Sedimentation and Aëration.**—The quality of the water is such that none of the methods of purification suggested by these questions are necessary.

**Filtration.**—All the water is filtered through sand filters. This system was adopted as being the best for the purpose, having regard to efficiency and cost.

**Total Area of Filter Beds.**—At Rivington, 6¼ acres.
At Vyrnwy, 6½ acres.

They are all open. The unfiltered water flows to the beds by gravity and the filtered water is drawn off by valves.

The average rate of filtration is about 450 gallons per square yard per day.

The service is not seriously affected by frost or ice, but during extreme cold the ice is kept broken for a narrow width at the sides.

The depth of filtering material is as follows:

| | Feet. |
|---|---|
| **Rivington Filter—** | |
| Sand | 2½ |
| Gravel and broken stones | 4 |
| **Vyrnwy Filters—** | |
| First Filters—Sand | 2 |
| Gravel | 1 |
| New Filters—Sand | 2½ |
| Gravel | 1 |

The cleaning is effected by scrapers or by spades and is required on an average about once a month.

In summer and autumn more frequent cleaning is occasionally required.

The sand is washed by machinery and replaced.

**Mechanical Filtration**—None.

**Fire Supply.**—This is taken from the general supply, but there are special fire mains throughout the businesss parts of the city. The water is

delivered in sufficient volume and under sufficient pressure to throw jets direct from the mains over the tallest buildings.

The total number of hydrants in the city is about 7400. There are also about 1000 old fire plugs of a type now being gradually replaced.

The cost of each single hydrant, as supplied by the manufacturer under contract ready for fixing, is £1.11.

**Standpipes.**—There is only one standpipe in use in connection with the gravitation supplies. This is for a high-pressure service in an elevated district, and consists of a circular wrought-iron tank, supported by masonry, and fixed at a height of 90 feet above the surface of the ground.

**Fire Hydrants.**—The hydrant in use is of the sluice-valve pattern with 3 inch outlet.

**Water Meters.**—The water supplied through meter is charged for at the uniform rate of 6d. per 1000 gallons.

**Employees.**—The number of employees fluctuates constantly according to the works in hand, especially as to the fluctuations of pipe-laying.

The permanent officers are appointed by the Water Committee of the corporation on the recommendation of the chief engineer.

Workmen who are paid by daily wages are appointed and removed by the engineer or by the superintendent under his direction.

**There are no Immediate Changes in Contemplation.**—Liverpool has never had an impure supply since waterworks were first established, more than a century ago.

**Sedimentation** has not been found necessary prior to filtration.